NATURAL HISTORY

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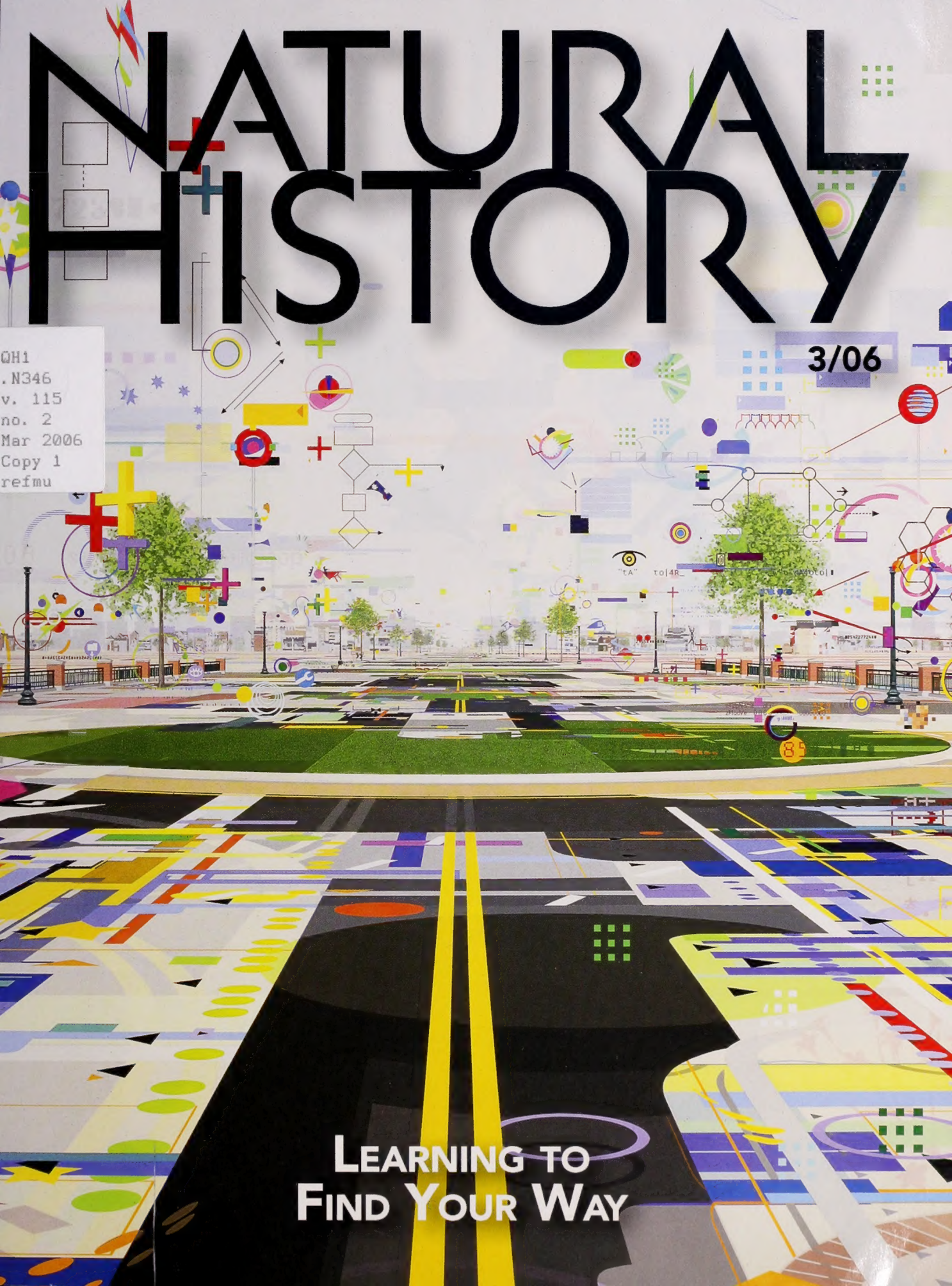

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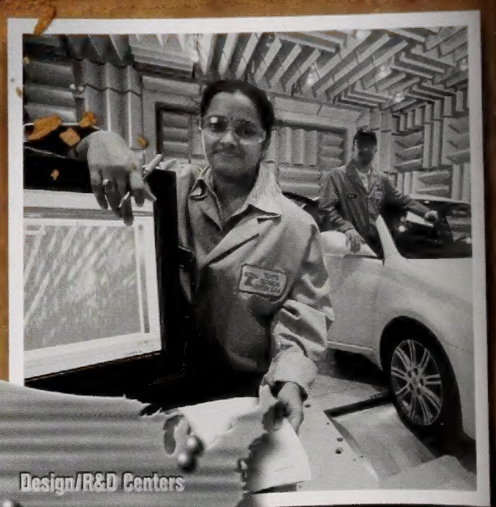

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MARCH 2006 VOLUME 115 NUMBER 2

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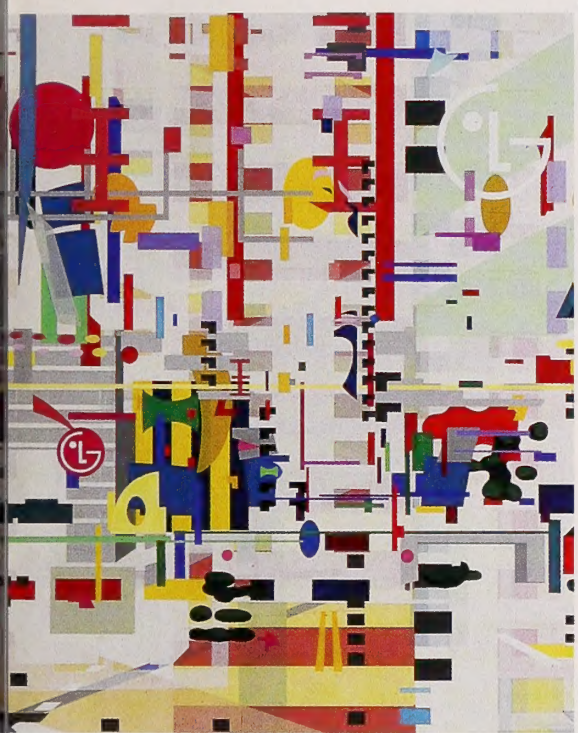

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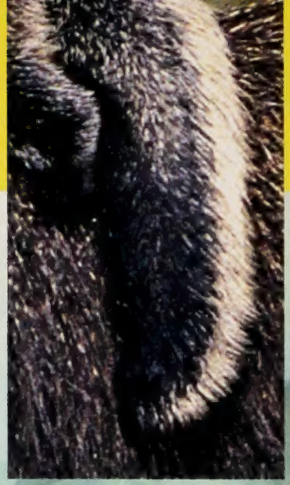

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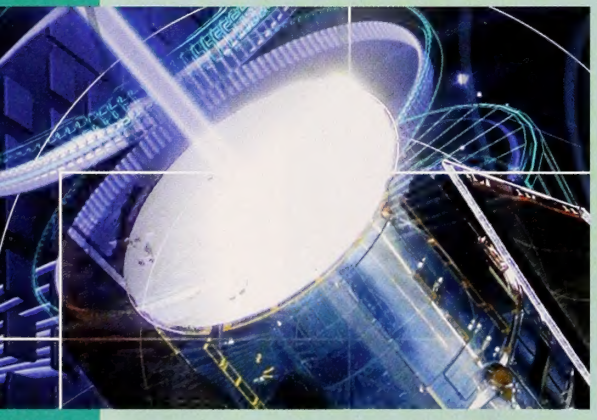

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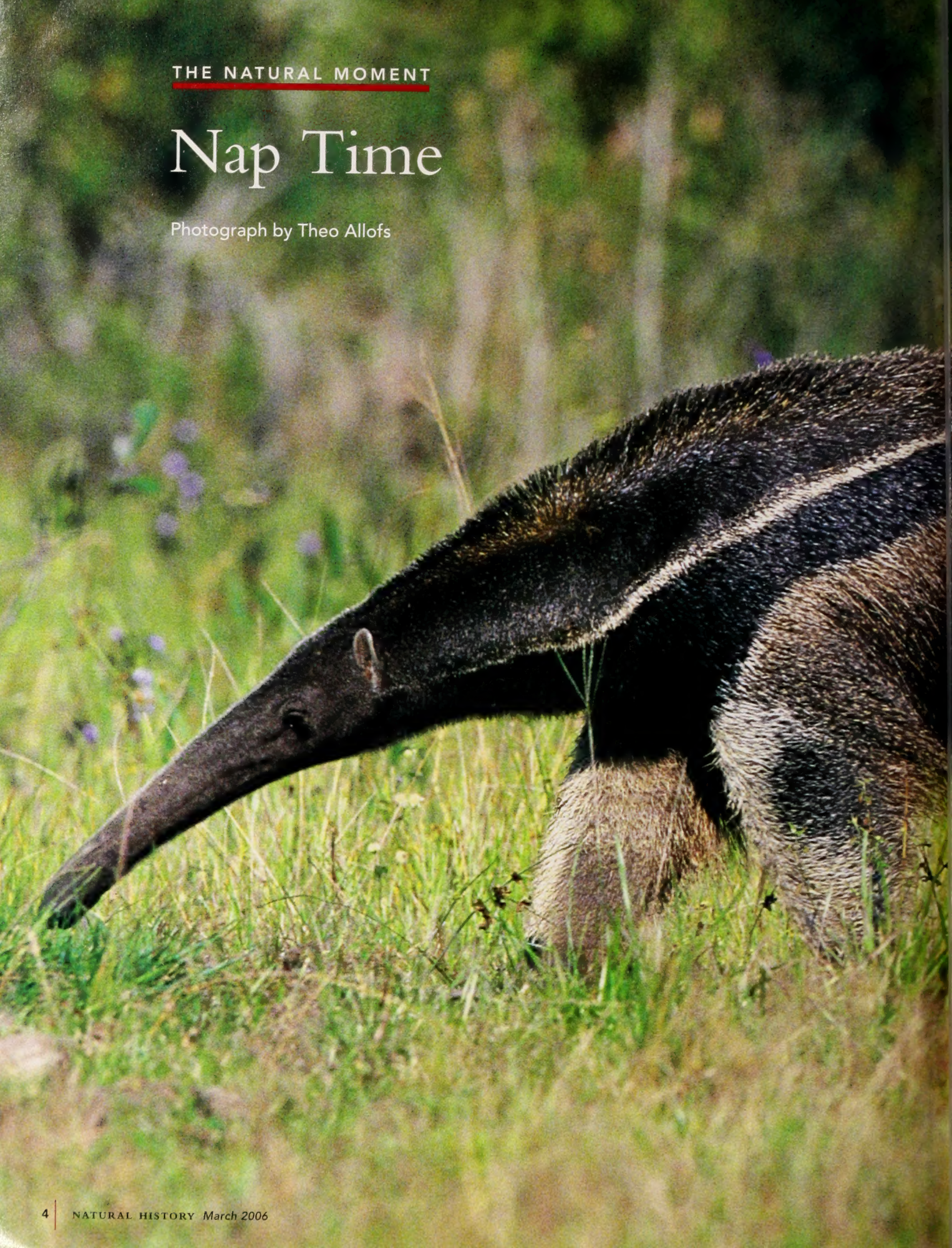
THE NATURAL MOMENT

Nap Time

Photograph by Theo Allofs



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The Pantanal is an immense floodplain that percolates through parts of Brazil, Bolivia, and Paraguay. About 80 percent of the land is deeded to cattle ranchers, yet remarkably, the area's patchwork of meadows and swamps still supports jabirus, jaguars, and peccaries. Another local exotic, the giant anteater *(Myrmecophaga tridactyla),* actually gets a calorie boost thanks to the farmed cattle. The anteater pictured here was going from one cow patty to the next, foraging for ants beneath the fertile droppings.

Snuffling through cow dung may be a good way to get a quick bite, but it hardly begins to show off the giant anteater's most amazing adaptation: its snout. The lower and upper jaws are joined to create a narrow tubelike mouth with no teeth. The animal can open its mouth slightly by rotating the lower jaw. That's gap enough for the anteater's sticky, two-foot-long tongue to dart out and extract some thirty thousand ants and termites a day.

In most circumstances giant anteaters forage alone. Mothers carrying young on their backs, papoose-style, are the exception. The prospect of catching a pair on film lured photographer Theo Allofs to the Pantanal seven times. Luck finally struck when Allofs—not imagining the animals would be active at midday—was in the midst of a siesta. After being roused, he raced off in pursuit. As he was getting this image, Allofs says he watched through his lens as stray ants scurried up the mother's snout, forcing her to stop periodically and brush them out of her eyes. —*Erin Espelie*

What Little Memories Are Made Of

Mitzi. Two syllables across time, and for Eric R. Kandel, the memories rush in. She sits on the edge of his child's bed, touches his face, opens her blouse. Would he like to touch her? She is the family housekeeper, from the working class, "an attractive, sensual young woman of about twenty-five." He is a boy of eight, the second son of a middle-class family living through the dying days of prewar Vienna, once the intellectual capital of Europe. A sophisticated culture swirls all around them, but of course he is much too young to imagine what secrets Mitzi has in store. "I barely grasped what she was talking about," he writes, from a vantage sixty-seven years later, "but her attempt at seduction had its effect on me, and I suddenly felt different than I ever had before."

Then, less than a year after his encounter with Mitzi: a terrible day. Soldiers bang on the door. You must leave at once. Hurriedly, he, his brother, and his mother gather a few bits of clothing and rush to the home of another family of Jews. His father, Hermann, is missing. The family, frantic with worry about Hermann, returns a few days later to find the house ransacked by the Nazis. But they are the lucky ones. Hermann served as a soldier in the First World War, and he can prove it. The family is reunited, emigrates from Austria, and begins a new life in America.

Memory has always fascinated me," Kandel writes, in his intellectual autobiography, *In Search of Memory* (forthcoming this month from W.W. Norton). With such vivid recollections of the past, is it any wonder? In "Learning to Find Your Way" (page 32), we draw excerpts from that book, which bears witness not only to memories of sexual awakenings and the early days of the Holocaust, but also to the discovery, decades later, of how such searing moments can be permanently preserved in neural pathways for instant recall. The study of memory lured Kandel away from a planned career as a psychoanalyst to the study of basic neurobiology and the neurophysiology of the brain. Kandel finds his compass in the writings of Freud himself: Psychoanalysis, Freud had insisted, would one day learn all it could learn about the unconscious by putting patients on the couch. The neurobiologist would explain more completely what the psychoanalyst could probe only superficially.

Fast-forward through a life of science, highlighted by Kandel's Nobel Prize–winning discoveries of how long-term memories are fixed at the cellular and molecular levels. Those biochemical underpinnings in place, Kandel and his students could explore one of the most intriguing questions at the intersection of philosophy, physics, and the study of the mind: how do animals—in particular, how does the human animal—represent memories of place?

—PETER BROWN

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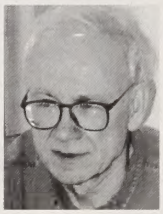
Based in Canada's Yukon Territory, wildlife and nature photographer **THEO ALLOFS** ("The Natural Moment," page 4) travels the globe to document endangered animals and their threatened habitats. Through his work he hopes to stimulate interest in preserving the natural world. Allofs's most recent book, *Pantanal: South America's Wetland Jewel* (Firefly Books, 2005), accomplishes just that for a rare ecosystem. His photographs have won several awards, including the *BBC Wildlife* Photographer of the Year competition and *Nature's Best Photography* Award. Selections of his work can be viewed at his Web site (www.theoallofs.com).

ERIC R. KANDEL ("Learning to Find Your Way," page 32) was born in Vienna, Austria. First captivated by history, psychoanalysis and psychiatry, Kandel later became interested in neurobiology, and finally in the biological processes of memory. He is University Professor and Fred Kavli Professor of Brain Science at Columbia University, and senior investigator at the Howard Hughes Medical Institute in Chevy Chase, Maryland. He has received fifteen honorary degrees and numerous prizes and awards, including the Lasker Award, the National Medal of Science, and the Wolf Prize of Israel. In 2000 he became the first American psychiatrist to be awarded the Nobel Prize in Physiology or Medicine. His intellectual autobiography, *In Search of Memory: The Emergence of a New Science of Mind,* from which the essay in this issue has been adapted, will be published by W.W. Norton this month.



College courses can have lasting effects not only on the students, but on the lecturer as well. **ULDIS ROZE** ("Smart Weapons," page 48) had just such an experience during his first job at Queens College in New York City. Even though his background was in chemistry and biochemistry, Roze taught a course in biology, and during field trips, he encountered nature's diversity. Stirred by the experience, Roze and his wife built a cabin at the edge of the woods. When porcupines ventured out of the woods at night, drawn by glue in the plywood of the cabin, Roze followed them, and they became his mentors. Some of what he learned he gathered in a book, *The North American Porcupine* (Smithsonian Institution Press, 1989) and in scientific papers. He retired from lecturing in 2003, but he continues to chronicle the lives of his forest visitors.

RUSSELL L. CIOCHON ("Our Anthropoid Roots," page 54) is no stranger to the pages of *Natural History,* having previously written not only about the fossil primates from Myanmar (formerly Burma) that he revisits in this issue, but also on various other paleontological and archaeological topics. A professor of anthropology at the University of Iowa in Iowa City, Ciochon has often collaborated with Chinese and Southeast Asian scholars in field research. **GREGG F. GUNNELL** became fascinated with the Burmese fossil primates as a graduate student, little suspecting he would ever study the fossils professionally. His research also focuses on the origin and diversification of North American bats, carnivores, and the hippolike anthracotheres. Gunnell is an associate research scientist and senior research museums collection manager at the University of Michigan Museum of Paleontology in Ann Arbor. Ciochon and Gunnell are collaborating on a book about ancient Burmese primates, which will be published in 2007.

Ciochon

Gunnell

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Natural History (ISSN 0028-0712) is published monthly, except for combined issues in July/August and December/January, by Natural History Magazine, Inc., in affiliation with the American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024. E-mail: nhmag@naturalhistorymag.com. Natural History Magazine, Inc., is solely responsible for editorial content and publishing practices. Subscriptions: $30.00 a year; for Canada and all other countries: $40.00 a year. Periodicals postage paid at New York, NY, and at additional mailing offices. Canada Publications Mail No. 40030827.
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Flying Reindeer

Piers Vitebsky ["A Winter Hunt," 12/05–1/06] provides a solid grounding in the history and ecology of place, and transports the reader through his descriptions: the tinkling of frozen tea crystals and someone "crunching off" as they walked away. The article also emphasizes how the author and most readers truly exist outside the reality of the Eveny and other subsistence-based peoples, when he flies away to teach and then easily flies back into their world. My only critique is that he didn't bring readers up to date with how life has changed as a result of the fall of the Soviet Union and the increasing effects of global climate change on Arctic regions and their inhabitants.

Susan A. Crate
George Mason University
Fairfax, Virginia

I nodded solemnly at Piers Vitebsky's line, that "domesticated" reindeer are "only weakly attached to people." As a Scandinavian descendant of those who roamed Arctic Finland and Sweden before 1900, I have collected stories of horrific accounts about reindeer. Most often the experiences were bone jarring (desperately clinging to a sledge that catapulted and tumbled through the semidarkness over treacherous tundra). Even experienced drivers were routinely bounced out of the sled and seriously injured or killed. Older children placed on reindeer commonly fell victim to a runaway mount. If they were foolish enough to hang on rather than fall off, they were not likely to be seen again.

Brenda Johnson Tzipori
Ventura, California

PIERS VITEBSKY REPLIES: Susan Crate is right to call attention to the fall of the Soviet Union. My book chronicles its impact on the personal, political, and spiritual lives of separate families. Environmental degradation is a concern, but the Eveny are highly adaptive. Sometimes they joke, "This is our home. If the climate gets hot, we'll just stay and herd camels!"

Brenda Johnson Tzipori's hair-raising stories are precious family heirlooms. As with car travel, the occasional disaster is much more memorable than the everyday, trouble-free journeys. Domestication is seen as a delicate social contract, and herders take pride in keeping reindeer cooperative rather than recalcitrant.

Symbiosis and Evolution

The November 2005 issue on evolution makes a conspicuous omission. None of the articles mention symbiosis as a major driving force of evolution, as articulated by Lynn Margulis's serial endosymbiosis theory. Margulis makes the compelling argument that wholesale combination of previously separate, free-living genomes into a single organism is perhaps the most important mechanism for creating new species. A classic example is the predation and incomplete digestion of one bacterium by another, leading ultimately to the nucleated cell.

Michael Duffin
Swanzey, New Hampshire

In Real Time

In his article "Evolution in Action" [11/05], Jonathan Weiner does an excellent job showing that evolutionary change can be rapid and can be studied as it occurs. He does, however, repeat an incorrect conclusion when he states that the story of the evolution of color in the peppered moth has "toppled over."

Research has repeatedly shown that natural selection acts on the color of moths and that changes in air quality lead to rapid evolutionary change. What is in doubt is the mechanism whereby natural selection occurs. Bernard Kettlewell's initial hypothesis was that selection favored moths that matched their background. As Mr. Weiner correctly notes, subsequent study has failed to support that mechanism, and investigators are now investigating other hypotheses.

Jonathan Losos
Washington University
Saint Louis, Missouri

JONATHAN WEINER REPLIES: Jonathan Losos is correct: the case of the peppered moth does remain a dramatic example of evolution in action. The moth has evolved before our eyes, and natural selection has driven its evolution.

The story of the moth should be taught in classrooms as a case study of both evolution in action, and also of science in action. When hard new data force scientists to question the details of a favorite old hypothesis, they do it—even if it hurts.

Flexibility Is Enough

One of the examples cited as a classic case of rapid evolution, in the chart on page 50 of Jonathan Weiner's article, warrants clarification. Our research

has shown that increased shell thickening in the marine snail *Littorina obtusata* can be induced by exposure to waterborne risk cues released by the predatory green crab. Those changes are the result of what is called phenotypic plasticity, and they can take place in as few as ninety days. Rapid evolution via natural selection need not be invoked to explain them.

Geoffrey C. Trussell
Northeastern University
Nahant, Massachusetts
Ron J. Etter
University of Massachusetts
Boston, Massachusetts

THE EDITORS REPLY:
Geoffrey C. Trussell and Ron J. Etter are correct, but the error was an editorial one, not Jonathan Wiener's. Their work on marine snails is an evolution story, but not really a story of evolution in action. Rather, as they state, it is a story of the evolution of phenotypic plasticity.

No Such Animal

In his otherwise outstanding article, "On Darwin's Shoulders" [11/05], Douglas J. Futuyma states that one species of whiptail lizard includes "both sexual and asexual types of females, yet the asexual type does not seem to come to dominate the population." But no such species exists: Most species of whiptail lizard include both males and females. But in other species, only females exist; they reproduce by cloning themselves from unfertilized eggs.

All the unisexual species of whiptails evolved as hybrids of two ancestral species that included both sexes and required fertilization to reproduce. In certain cases, one of the resultant hybrid females was able to clone herself instead of being sterile, like a mule. The outcome is often that both ancestral species and the new unisexual clone survive. Individuals of the all-female species can disperse and colonize new localities, with no dependence on their ancestors or on males.
Charles J. Cole
American Museum of Natural History
New York, New York

DOUGLAS J. FUTUYMA REPLIES: Charles J. Cole is correct; I should have referred to the hybrid origin of the all-female populations of whiptail lizards. There are other animals, though, such as the fall cankerworm moth, in which asexual female lineages that have not originated by hybridization coexist with sexual forms of the same species. My point remains, however, that no one knows why the sexual species of whiptails persist, despite the higher potential rate of population growth among the asexual species.

Darts and Laurels

I was disappointed by Neil deGrasse Tyson's article, "The Perimeter of Ignorance" [11/05]. I'm not a proponent of intelligent design; in fact, I strongly disagree with much of it. But the tone of the article seemed to attack more than just intelligent design; it attacked the belief in God in general. Many religious people do not believe that God precludes evolution, and vice versa. Educate me about science and nature, but don't patronize me for believing in God.
Joshua Boyle
Mesa, Arizona

I've read every single issue of your magazine for more than twenty years. One of the greatest blows to me was the passing of Stephen Jay Gould. He was my favorite professor in college, and his columns were an unalloyed pleasure. Although I enjoyed Neil DeGrasse Tyson's columns, I had vaguely lamented his promotion to the monthly replacement for Gould.

Mr. Tyson, I owe you an apology. Your November 2005 column is the finest science writing I've read in several years. I laughed a few times, my eyes misted up at other times, I learned a fair bit, and I was thoroughly engaged by every single word. You have justly inherited the mantle of monthly mentor for *Natural History*. Gould would have been proud to have penned such a gripping essay.
Albert C. P. Doyle Jr.
Boston, Massachusetts

NEIL DEGRASSE TYSON REPLIES: I am grateful for the responses (even the negative ones) to my article, and I am especially honored by Albert C. P. Doyle Jr.'s comparison with Stephen Jay Gould, who practically invented the modern essay form in these pages. But I wish to reply specifically to Joshua Boyle, who was offended by the article's tone. I had never intended, either in content or tone, to suggest that God does not exist. And I thought I had made it clear that many contemporary scientists believe in God. But I am nonetheless led to the famous quote from Harry S Truman: When a campaign supporter shouted, "Give 'em hell, Harry!" Truman replied, "I don't give them hell. I just tell the truth and they think it's hell."

Teaching the Controversy

I find Peter Brown's editorial, "Disciplined Change" [10/05] a bit disturbing. That scientific debate is "not for the uninformed," and that "scientific controversy is for scientists," seems to imply that we should not acknowledge that any disagreement exists concerning theories that have been approved by scientists.

I remember the attitude of my own biology professor—a man devoted to the "scientific method"—to the theory of continental drift. He expressed outrage over the idea that continents could in any way have floated or moved to their mid-twentieth century position. Since then, I understand that many scientists with their scientific "union cards" have come to support that theory.

The moral of the story is that I was not harmed by knowing that the big guys in science disagreed over a theory. I fear that you put yourselves into the position of those who say, "Don't ask questions, just believe," when you recommend not raising any controversy at the high school level.
Anne Graves
Houston, Texas

Peter Brown's editorial points out that the nature of scientific inquiry is widely misunderstood. "Science is a method, not a set of conclusions," he writes, insisting that science does not grant equal validity to different opinions. Students are well aware of the controversy of teaching evolution in schools, if not its particulars. Ignoring the call by proponents of intelligent design to "teach the controversy" can give students the impression that closed-minded teachers are unfairly indoctrinating them. A better approach would be for science teachers in all disciplines to use their first class to explain and review the scientific method. At the end of this class, they could announce that the semester is to be devoted to what we think we know about the matter at hand, which is always subject to disciplined change.
Peter Starr
Albuquerque, New Mexico

PETER BROWN REPLIES: As perceptive commentators have pointed out recently, the slogan adopted by the proponents of "intelligent design" ("teach the controversy") has its genesis in humanistic, postmodern academic views. Ironically the relativism of those

(Continued on page 74)

Harbor Hopping in New England

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How Does the Greenhouse Grow?

"Everyone knows" that plants are helping to put the brakes on global warming by absorbing greenhouse gases. But two new studies show that the plant kingdom won't brake the warming trend quite as hard as everyone has assumed.

Astonishingly, plants may produce as much as a third of the methane, an important greenhouse gas, that is released into the atmosphere each year. An international team led by Frank Keppler, a geochemist at the Max Planck Institute for Nuclear Physics in Germany, placed plants and leaves in separate sealed chambers containing methane-free air. After a set time they analyzed the air, and discovered that both living plants and dead leaves make methane, though living plants make much more. What's more, both living and dead vegetation do it aerobically, contradicting the generally accepted view that when methane is produced biologically, oxygen must be absent. Both how plants make methane and how science previously failed to detect the process remain mysteries.

Another international team, led by Andrei Lapenis, a climatologist at the University at Albany in New York, investigated a puzzling discrepancy in Russia's boreal forest. Satellite images indicated a dramatic proliferation of greenery in recent decades, which climatologists have taken to mean the trees were absorbing extra carbon dioxide in response to warmer, wetter weather. On-the-ground surveys, however, showed a much smaller growth spurt.

After examining fifty years of forestry records, Lapenis and his colleagues concluded that the Russian trees had made a surprising shift. They were producing much more foliage than before, but only a little more wood. Trees store carbon much longer in branches and trunks than in relatively disposable leaves and needles. As a result, Lapenis expects that though trees will absorb more carbon as the climate changes, the increase will be only a third as large as expected.

It seems that the more we need trees to clean up after us, the less obliging they turn out to be. (*Nature* **439:**187–91, 2006; *Global Change Biology* **11:**2090–102, 2005)

—Samantha Harvey

Solitary (left) and swarming (right) forms of African desert locust

Ain't No Ocean Wide Enough

In October 1988, ships off the coast of Africa reported massive swarms of desert locusts (*Schistocerca gregaria*) flying west over the Atlantic. A few days later some of the insects turned up on Caribbean islands, exhausted but alive. That 1988 exploit may have been a rare repeat performance of a momentous event, according to Nathan R. Lovejoy, a zoologist at the University of Toronto, and several U.S. colleagues. After analyzing *Schistocerca* DNA, the team concluded that an ancestral locust from Africa gave rise to not only the African desert locust, but also to the fifty-odd *Schistocerca* species of the Americas, which includes grasshoppers, as well as locusts. The DNA points to a single colonization between three and five million years ago.

The superinsects that made the epic crossing probably got help from thermal updrafts. Once lofted to 6,000 feet, strong westward winds could have rushed them along to their new home. (*Proceedings of the Royal Society* B, in press)

—Stéphan Reebs

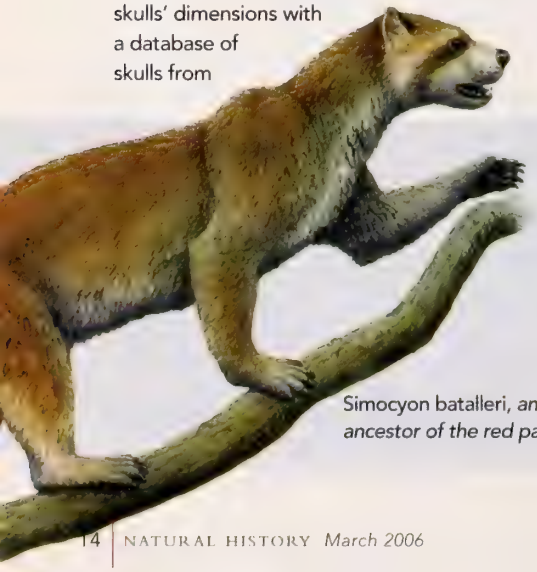
Immigration Reform

Who were the New World's first inhabitants? The ancestors of present-day Native Americans are thought to have come from northern Asia, but new research bolsters the theory that another group arrived first.

Walter A. Neves and Mark Hubbe, anthropologists at the University of São Paulo in Brazil, examined eighty-one skulls that were unearthed from the Lagoa Santa region of central Brazil. The skulls—all between 7,500 and 11,000 years old—belonged to members of the group thought to have been the first Americans. The anthropologists compared the skulls' dimensions with a database of skulls from five continents. Their finding: the skulls of ancient Americans most closely resemble those of present-day Australians and Melanesians.

Intriguingly, people with similar skulls are known to have lived in east Asia 20,000 years ago. Sometime earlier, ancestors of this group had likely split off to colonize Australia and Melanesia. The anthropologists theorize that members of the east Asian contingent migrated to the New World via the Bering Strait some 15,000 years ago. North Asians, forbears of modern aboriginal Americans, likely followed soon after. The fate of the Americas' first colonists is still unknown. (*PNAS* **102:**18309-14, 2005)

—Sion E. Rogers



Simocyon batalleri, *an ancestor of the red panda*

Thumbs Up

Only two panda species survive, but thanks to the late Stephen Jay Gould, their "thumbs" are immortal. For Gould, the panda's curious extra digit illustrated how natural selection solves problems by refashioning new body parts out of old ones. The panda's "false" thumb is formed from a highly modified wrist bone; it's handy for holding the panda's favorite food, bamboo. In fact, the panda's dietary fondness for bamboo has long been held as the driving force behind the evolution of the thumb in both the red and the giant panda.

But Manuel J. Salesa, a paleobiologist at the National Natural History Museum in Madrid, and his colleagues have found a forerunner, at least in the red panda's case. An extinct relative of the red panda, *Simocyon*

Cannibal Canard

Three years ago a well-publicized study suggested that consumption of human flesh might have been widespread among our early ancestors. New research shows, however, that we may not be descended from cannibals, after all.

The evidence that cannibalism was once rampant came from a study of elderly women of the Fore people of Papua New Guinea. The women had practiced ritual cannibalism as children, but they had escaped a disease called kuru that was transmitted by the ritual. (Kuru killed many Fore before cannibalism was banned in the 1950s.) Kuru, like mad cow disease and Creutzfeldt-Jakob disease, is caused by the abnormal development of proteins called prions; in the so-called prion diseases, the abnormal prion proteins cause brain tissue to degenerate.

Prion proteins are encoded by a single gene known as *PRNP*, and people with certain variations of that gene are resistant to the prion diseases. Indeed, the 2003 study showed, the elderly Fore women were more likely to have a protective gene variation than their kin who never practiced cannibalism. Presumably, most cannibals without the protective gene had succumbed to kuru. Surprisingly, the study turned up the same protective gene variation in people throughout the world, suggesting that prion disease—and by extension, cannibalism—was once common.

But Marta Soldevila and Jaume Bertranpetit, both evolutionary biologists at Pompeu Fabra University in Barcelona, and their collaborators now beg to differ. They examined the *PRNP* gene of 174 people from around the world, and considered all the gene's possible variations—something the earlier study did not do. The team found that the disease-resistant variation of the gene is statistically rare enough to rule out a kuru-haunted past. (*Genome Research* **16**:231–9, 2006) —*S.R.*

Cannibals preparing a feast, 16th century

Worm Sperm

For some worms, sex is a prickly affair. During copulation, specialized bristles on the worm pierce its partner's skin and inject a substance. The role of the substance has remained mysterious—but it isn't sperm, which is transferred separately. Now Joris M. Koene, a biologist at Vrije University in Amsterdam, and his colleagues have solved much of the mystery by removing the bristles of common earthworms and observing what happened when they mated.

Earthworms, of course, are hermaphroditic. The female part of the earthworm, *Lumbricus terrestris*, includes four so-called spermathecae, storage tanks for the sperm they receive. Worms can probably fill their sperm tanks selectively, digesting any unwanted sperm therein. Because they are promiscuous creatures, the process may enable them to choose which of their partners' sperm fertilizes their eggs. Worms whose mating partners were artificially bristle-free, however, exerted even greater control: they distributed their partners' sperm less evenly among their four sperm tanks and took in less sperm than they would have from normal, bristly mates. The mystery substance, then, appears to be a weapon to override partner choice, and maximize a worm's chances that its sperm is stored and used.

Darwin thought sexual manipulation by one sex at the expense of the other would not evolve in hermaphrodites, since any individual would simultaneously reap both the gains and the pains. But in fact, sexual manipulation by hermaphrodites is perfectly compatible with evolution by sexual selection. Once a beneficial sex-specific strategy evolves, any hermaphrodite that has it outperforms those that lack it, and the strategy quickly spreads to the entire population. (*Behavioral Ecology and Sociobiology* **59**:243–9, 2005) —*S.R.*

Even hermaphrodites fight the battle of the sexes.

batalleri, was discovered recently with a false thumb, as well. The digit probably helped the carnivorous panda ancestor climb trees; only later did the red panda's thumb become useful for holding bamboo. The giant panda, however, is not closely related to *S. batalleri*, and its thumb probably evolved independently. Maybe, for the giant panda, the bamboo explanation still holds. (*PNAS* **103**:379–82, 2006) —*Nick W. Atkinson*

Scent of a Mushroom

Organisms that give advance notice to would-be attackers about their toxic defenses are no evolutionary paradox: a predator's attack, even if ultimately thwarted, can still harm a poisonous organism. So why, asked Thomas N. Sherratt, an evolutionary biologist at Carleton University in Ottawa, Ontario, and his colleagues, do so many poisonous mushrooms seem so secretive about their hazards?

To find the answer, the investigators carried out the first formal analysis of the characteristics associated with poisonous mushroom species in both North America and Europe. They discovered that although poisonous mushrooms aren't generally more colorful than their harmless counterparts, they do have more distinctive odors. One possible advantage of warning by scent (and possibly by taste) instead of by coloration might be that fungivores tend to forage for mushrooms at night, when color vision is less effective than a keen sense of smell. (*The American Naturalist* **166**:767–75, 2005) —*N.W.A.*

Love Potion

Musth is the annual season of sexual activity and aggression in male elephants. Glands on the male's face release frontalin, a pheromone that comes in two highly similar forms. In fact, the molecule of one is simply the mirror image of the other. New research shows it's the ratio of the two forms that matters to other elephants.

A team biologists led by David R. Greenwood of HortResearch in Auckland, New Zealand, discovered that adult male Asian elephants secrete nearly equal amounts of the two forms of frontalin. The secretions are most evenly balanced during the peak of musth. Juveniles, by contrast, secrete lower concentrations of both forms than adults do, and the balance is skewed in favor of one of the forms.

The biologists presented elephants with mixtures of the two frontalin forms in differing ratios. Males and nonovulating females moved away from balanced secretions—the equivalent of giving a wide berth to a horny male who's itching for a fight. Ovulating females had just the opposite reaction: they actively sniffed and stayed close to the samples. What's more, receptive females preferred the most evenly balanced mixtures, Greenwood says. Apparently that's the recipe for elephant romance. (*Nature* **438**:1097–8, 2005) —*S.R.*

Under the influence of pheromones?

Three Stars in One

The most familiar twinkle in the night sky has been keeping a secret. The North Star, it turns out, is not just the two stars (Polaris and a smaller companion) that were already known. Astronomers have now caught sight of number three—though just barely. Nancy Evans of the Harvard–Smithsonian Center for Astrophysics in Cambridge, Massachusetts, and her colleagues needed the full optical power of the Hubble Space Telescope to see it. The third star is so small, and so "close" to Polaris (about 2 billion miles, or roughly the distance between our Sun and the planet Uranus), that it's all but washed out in the glare of the main star. —*S.R.*

Jamming the Signal

Most moths' ears have evolved for one purpose: to help the moth avoid being eaten by a bat. Moth ears are tuned to hear bat echolocation calls, which trigger behaviors in the moth that help it escape. Many moth species may even foil bat attacks by mimicking the calls of a bat on the hunt. The resulting cacophony may so confuse the bat—in effect, jamming its "radar"—that it fails to locate its prey. A bat may also learn to associate the clicking sounds of a moth with an unpalatable meal, reducing the chances that the bat will attack.

Surprisingly, though, no one had ever recorded and studied moth clicks during a bat attack under natural conditions. Now two sensory ecologists, John M. Ratcliffe of Cornell University in Ithaca, New York, and James H. Fullard of the University of Toronto in Ontario, have done just that. They observed that moth sounds did affect bat predation, but only during aerial attacks.

Just as the bat is making its final decision to attack—about half a second before reaching its target—a dogbane tiger moth begins emitting clicks from organs called tymbals, on the thorax. Although such a delayed defense makes for close calls, it usually works: moths with intact tymbals were attacked significantly less often than were moths whose tymbals had been disabled by the investigators. (*The Journal of Experimental Biology* **208**:4689–98, 2005) —*N.W.A.*

Sneaky Genes

Some bacteria are masters of deception. Take *Pseudomonas syringae*, the species that causes halo blight, a devastating disease in bean crops. When the bacteria infect a bean plant, they release proteins that disable the plant's defense system. Resistant varieties of bean, however, have come up with a countermeasure. They recognize the hostile proteins and respond by releasing antimicrobial compounds. That's when the bacteria turn sneaky. Subsequent generations lose the genes that encode the offending proteins. Once they no longer trigger the plant's defenses, they steal in to launch a ferocious infection. But how and when do the bacteria unload the genes?

Two molecular plant pathologists, Andrew R. Pitman of the University of the West of England in Bristol and John W. Mansfield of Imperial College London, and their colleagues infected a resistant variety of the common bean *Phaseolus vulgaris* with the halo-blight pathogen and analyzed the resulting bacterial genome. They discovered that the bacteria respond to the plant's defenses by jettisoning a portion of their DNA that includes a gene for one of the proteins in question. Along with the protein-coding gene go other advantageous, though not essential, genes. But a puzzle remains: Why does the species retain the genes that betray its presence to the plant in the first place? (*Current Biology* **15**:2230–5, 2005) —*Graciela Flores*

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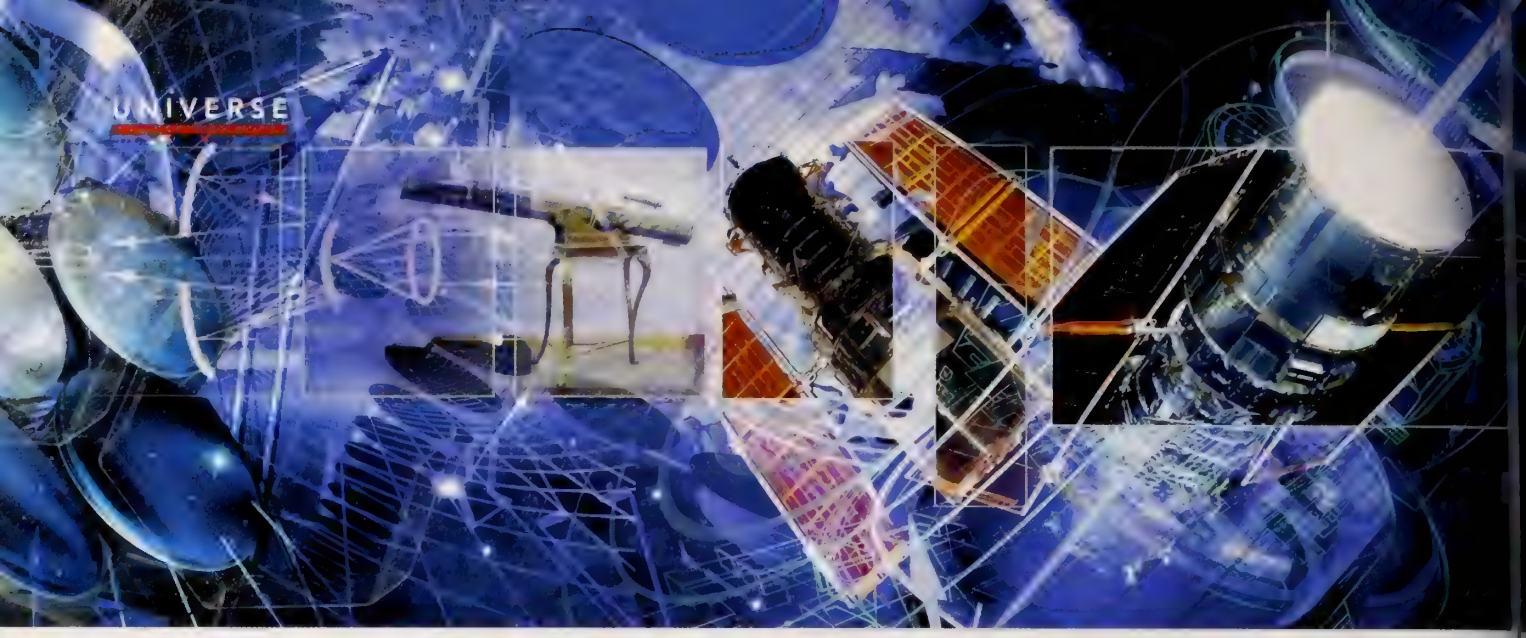

The Light Brigade

"More light!" cried the poet Goethe just before he died. For centuries, every sky watcher has said the same.

By Neil deGrasse Tyson

Astrophysicists are a proximity-challenged lot. Most of the objects of our affection lie forever out of reach and are, at best, barely visible from Earth. They release stupendous energy, are immune to manipulation, and don't grow in a laboratory. For the most part they are accessible only by night. We can't easily visit them in their natural habitat, and it's not yet possible to touch them. In our study of the contents and behavior of the universe, we deduce nearly everything we know from the analysis of light. Though smitten by the cosmos, astrophysicists have no choice but to embrace it from multiple degrees of separation: when we want to know the motions of a star, we examine not the star itself, not an image of the star, not even the spectrum derived from the light recorded in an image of the star, but rather the shifts in the patterns in the spectrum derived from the light recorded in an image of the star. It's a convoluted consummation, but it works.

Clearly, astrophysicists need more than eyes to accomplish these tasks. On its own, the eye is a good detector but not a great one—able to resolve visual data no finer than about one-sixtieth of one degree of a complete, 360-degree circle. In the dark, the pupil expands to about a quarter-inch across, and so it registers only a fraction of the ubiquitous light radiated by celestial bodies. Visible light ranges in wavelength by less than a factor of two, from 400 to 700 nanometers—a mere sliver of the full electromagnetic spectrum. For comparison, the wavelengths of the entire spectrum range from less than half a millionth of a billionth of an inch (high-frequency gamma rays) to hundreds of miles (extremely low frequency radio waves), a factor of more than 10,000 billion billion. Without a lot of help, we'd never detect most of what exists and takes place even in the visible cosmos, let alone the multitudinous happenings in all the nonvisible wavelengths of light.

Serious help in seeing at a distance arrived just four centuries ago, in the form of a pair of cookie-size lenses firmly fixed inside a tube and presented in September 1608 to Prince Maurice of Nassau, Stadholder of the United Provinces of the Netherlands, by a spectacle maker named Hans Lipperhey. His tube was the first historically substantiated, honest-to-goodness telescope, though allusions to earlier ones abound. Within half a year Galileo had learned of Lipperhey's indispensable instrument and had built a better one of his own design. By the autumn of 1609 he was gazing at the Sun, Moon, planets, and stars. He was about to show that Copernicus was right: the planets and their moons do indeed revolve around

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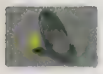

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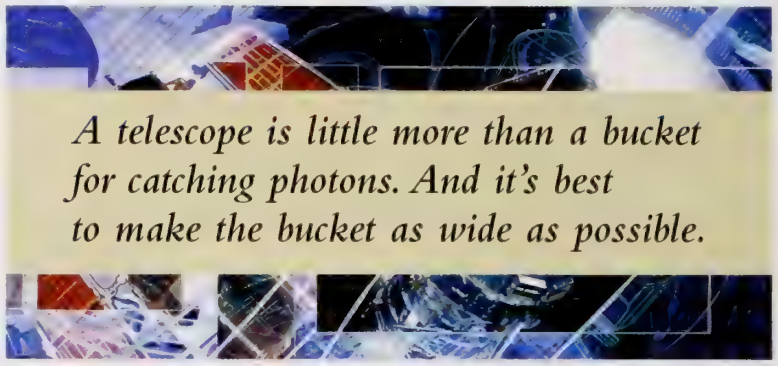
the Sun, not the Earth. And the instrument was soon to be given such names as *perspicillum* (Galileo's own choice of terminology, from the Latin for "seeing through"), perspective-glasse, spyglass, starrie tubus, and of course *telescopium* (from the Greek for "far-seeing").

If modern astronomy is the child of the telescope, modern astrophysics is the child of astronomy. Its midwives were two nineteenth-century technological innovations. The first was photography, literally "light drawing," which yielded straightforward evidence of an object's existence and visible features. The second was spectroscopy, which separates light into its component colors and enables us to glean scads of information about its source. Today we astrophysicists carry out observations and analyses with the aid of telescopes that collect tens of thousands of times more light than did Galileo's first attempts at a spyglass. In addition, we're armed with dozens of auxiliary tools—adaptive optics, digital detectors, spectrometers, supercomputers. But no matter the innovations, no matter the complexity of the technology, the astrophysicist's fundamental challenge is to collect light from dim and distant objects, and then extract from that light as much information as possible.



A telescope is little more than a bucket for catching photons. And it's best to make the bucket as wide as possible.

Telescopes make it possible for you to detect things too faint to see and to resolve detail where your eyes would otherwise fail you. But a telescope is little more than a bucket for catching photons of light that happen your way. Whether your goal is detection or resolution, the bigger your bucket, the better off you'll be. For a circular bucket the collection area increases as the square of the diameter, and so if you triple the diameter, you increase the bucket's capacity for detection ninefold. (Same math applies to the famous pizza equation: a ten-inch pie ($10\times10=100$) has more than twice the area of a seven-inch pie ($7\times7=49$).) And because the capacity to resolve detail comes from the width of your lens divided by the wavelength of light you're measuring, you always want the bucket to be much, much wider than the wavelength of light you're observing—in fact, as wide as you can afford to make it.

The telescopes built by Galileo were good enough to detect a couple of auxiliary shapes in Saturn's vicinity, but none of his telescopes could resolve them into a clear image of the planet's ring system. Half a century later, Christiaan Huygens's telescope resolved the shapes into one ring—not just because Huygens had a bigger telescope, which could collect more light, but also because he had a better telescope. Its lenses were more cleverly shaped and more cleverly positioned in the tube than the lenses in Galileo's instruments. But Huygens's discovery was only the beginning. Subsequent telescopes with ever-better resolution showed the single, wide ring to be made up of two, then several, then many rings. Ultimately, countless internal ringlets of the system revealed themselves in images taken by space probes [*see "Ringside Seat," by Neil deGrasse Tyson, October 2004*].

Lens shape and focal length are two other telescopic features to consider. When the telescope was an infant invention, and visible light was the only kind of light people were trying to snare, the lens closest to the object—the objective lens—was convex. Like all lenses, it refracted, or bent, the light rays that passed through it and brought them to a focus somewhere down the tube. The objective lens was the centerpiece of every telescope. It was also a big headache. Its glass had to be free of impurities and its surface unmarred; in addition, the shape of the lens had to be true to the curvature of a sphere. Glassmakers of the seventeenth century could meet those specs. But getting all the rays of light to come into focus at the same point was quite another matter. Steeply curved lenses can cause the light that passes through their various parts to focus at different points along the tube, creating blurriness—spherical aberration—in the image. Mildly curved lenses are better, but the problem persists.

There's an even more pernicious focusing problem, though. Whenever a ray of light passes at an angle from one medium to another of different density—from air to glass, from glass back into air, even from one kind of lens into another kind of lens—not only does the passage bend the light, but it also splits the light into its component colors, or wavelengths. Trouble is, each color of light bends at a slightly different angle, and so it comes into focus at a slightly different point. When you're looking through a lens, whichever color you focus on—red, green, blue, or anywhere else in the rainbow—you see that color at the center of the object, surrounded by fuzzy rings of each of the remaining colors. The whole dismal effect is called chromatic aberration.

By the mid-seventeenth century, a common way to correct for both kinds of aberration was to add more lenses to your telescope. The idea was that the light rays would bend and re-bend, refract and re-refract, and eventually come to focus in the same plane. The lenses had to be positioned in a clever sequence and at just the right position along the length of the tube. Some

(Continued on page 29)

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Clockwise from top left: Texas is famous for its ubiquitous wildflowers, including the bluebonnet, the State flower; a Spanish mission in El Paso showcases Texas heritage; the Rio Grande winds through Big Bend National Park; the Texas longhorn, descended from cattle brought over by Columbus more than 500 years ago; and an anhinga diving for food.

Texas is the most popular birding destination in the United States, according to the American Birding Association. The state is at the confluence of three migratory paths, and Big Bend National Park alone has 475 species—more than any other national park. About 75 percent of the species are found along the Texas Gulf Coast. Birders head to several spots along the Great Texas Coastal Birding Trail, a highway trail connecting established and new birding sites along the 624 miles of Texas coast. Highlights on the trail include the Aransas National Refuge, located on a broad peninsula north of Rockport. This is the principal wintering ground for the majestic and nearly extinct whooping crane, famous for its mating dance. Four hundred other species are found here.

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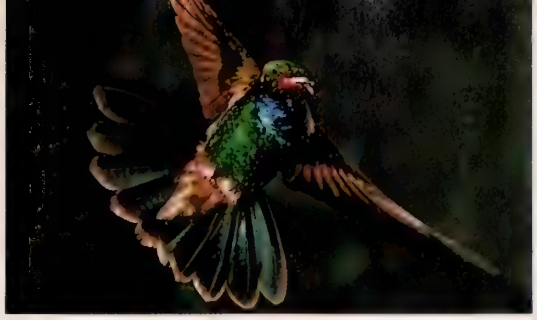
From top left: Petroglyphs in the foothills surrounding Tucson overlook the Sonoran Desert; a tram ride to the top of Sabino Canyon; a hummingbird in flight over the Santa Cruz River Valley; along the trail at Sabino Canyon

TUCSON

This charming city, with its adobe houses and Spanish colonial heritage, has mild weather year-round, making it ideal for hiking and bike riding, rock climbing, caving, and many other outdoor activities.

Mention Tucson and most people think of tall saguaro cacti and lush desert—but Arizona's second-largest city is surrounded by mountains and canyons, state and national forests, rivers, and waterfalls.

Sabino Canyon, located in the Santa Catalina Mountain range of the Coronado National Forest, boasts spectacular desert landscapes; with palo verde trees, cholla and prickly pear cactus, and groves of ocotillo. Take the Bear Canyon Trail tram and then hike the 2.5-mile trail across Sabino Creek, lined with cottonwoods, to Seven Falls, where you can splash about in or simply relax by clear-running pools of water. For more leisurely exploration, take a narrated tram to the top of the canyon. Keep an eye out for the



collared peccaries, tarantulas, white-tailed deer, lizards, and snakes that make their home in the recreational area.

Don't leave Tucson without a visit to Saguaro National Park, where you can see majestic saguaros, in all shapes and sizes (some reach 50 feet), and learn more about our stunning Sonoran Desert. Drive on a scenic loop or explore some of the more than 150 miles of hiking trails, ranging from easy strolls to steep, intense, and rugged hikes into the Rincon Mountains.

Learn about the Spanish colonization of the Southwest on the Juan Bautista de Anza Trail, who in 1775–76 established an emigration and supply route from Tubac, south of Tucson, to California. The Santa Cruz River Valley, also south of Tucson, is up for status as a National Heritage Area because of its cultural and historic riches—it has many Native American archaeological ruins and was a center of Spanish colonial exploration. It's also a world-class place for birding; look for elegant trogons and blue-throated hummingbirds in the Santa Rita and Santa Catalina Mountains and summer tanagers in the tall riparian forests near Tumacácori.

AND FOR A RELAXED WAY TO ENJOY THE OUTDOORS, visitors can catch a Major League Baseball game nearly every day in March. Tucson is the springtime home of three big league teams—the Diamondbacks, the Rockies, and the 2005 World Champion White Sox—more than any other Spring Training city.

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Alabama Gulf Coast Convention & Visitors Bureau

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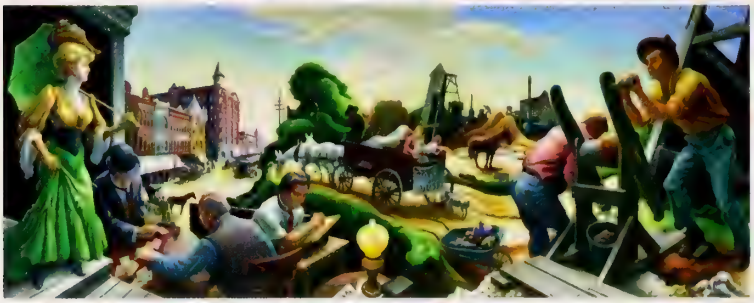
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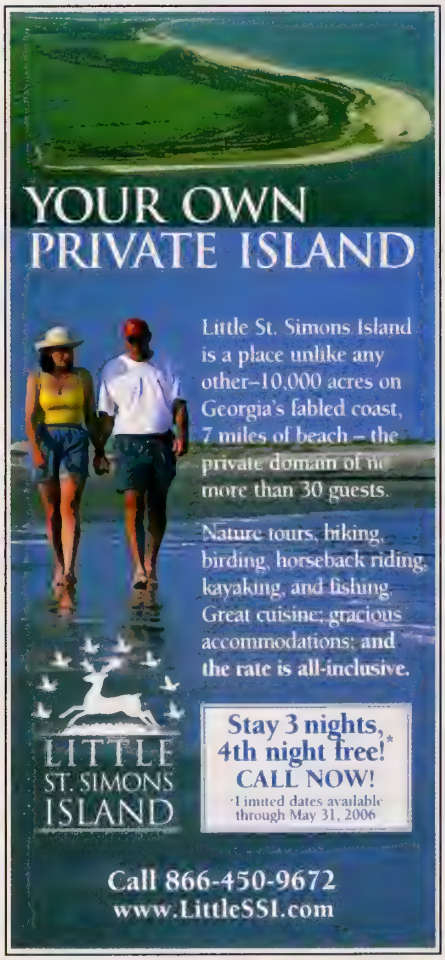

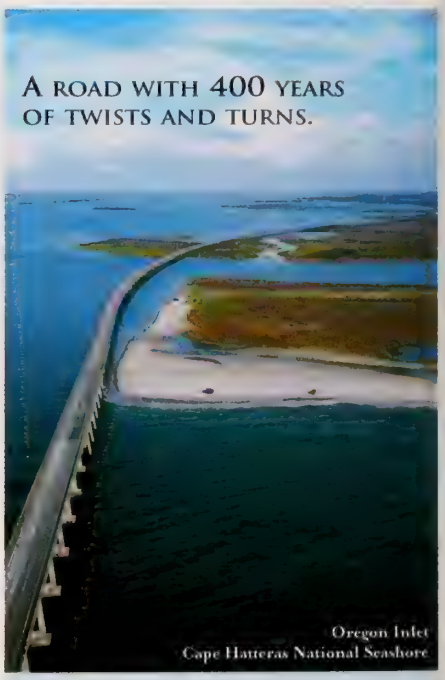

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 (Continued from page 20)

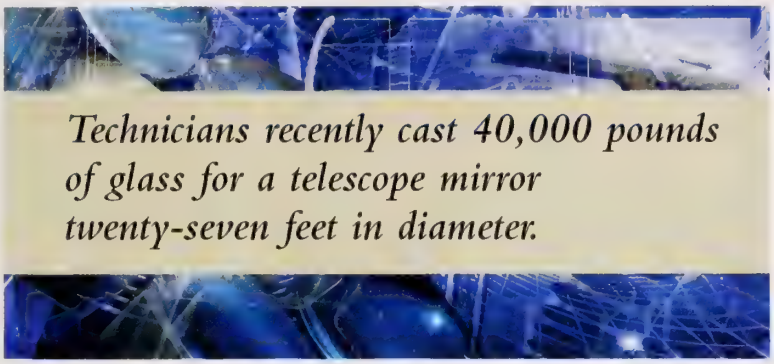
might have one flat side, and the amount of curvature on the other side might vary. Others might be made of glass of a different density. But despite all the challenges, some astronomers and opticians built some impressive refracting telescopes.

Lenses refract; mirrors reflect. Both relay light from one place to another. The tenth-century Iraqi mathematician Abu Ali al-Hasan ibn al-Haytham (Alhazen) understood this. Galileo understood this. Descartes understood this. Seventeenth-century astronomers quickly realized that using a mirror rather than a lens could eliminate chromatic aberration. Instead of being bent out of shape and refracted into its component colors, light would just bounce off the mirror—intact.

Unlike the silver- or aluminum-backed transparent glass mirrors with which people mercilessly examine their personal flaws, astronomical mirrors can be made of an opaque, polished material. In fact, they have to be: the light rays must be reflected off a front surface, not refracted through intervening glass. So the entire back, not merely the edges, of an astronomical mirror can be designed to strengthen and support the mirror. The size of any mirror designed on this principle can far surpass the size of a clear, refracting lens. But how do you look at the focused light without having your head get in the way?

Enter Isaac Newton and the reflecting telescope, closely preceded and followed by a couple of less famous contemporaries. Farewell, chromatic aberration.

Newton made his mirrors of copper-tin alloy, with a pinch of arsenic to increase the alloy's reflectivity. And instead of applying his powdery polishing abrasive with leather or cloth, he used pitch—a method still popular today. As for the best shape and arrangement for his telescope's components, Newton's solution was simplicity itself: a large, concave primary mirror collects and reflects the light onto a smaller, flat, tilted secondary mirror. The secondary mirror redirects the reflected light out the side of the tube; since it is flat, the secondary doesn't alter the image except to swap left with right. The viewer looks at the image in the secondary mirror through an eyepiece inserted in the side of the tube, happily removed from the path of the light entering at the front. Although the primary mirror of Newton's telescope was less than an inch and a half across, and its metal less than brilliantly reflective, on January 11, 1672, Newton demonstrated its workings for members of the scientific organization known (both then and now) as the Royal Society. Duly impressed, they awarded him the rank of Fellow.



Technicians recently cast 40,000 pounds of glass for a telescope mirror twenty-seven feet in diameter.

Improvements and enlargements followed fast and furious. Nowadays the most massive, most modern, and most famous telescopes, regardless of the wavelengths they gather, all rely on mirrors rather than lenses as their primary light bucket. Just this past November, astronomers and technicians at the University of Arizona in Tucson finished casting 40,000 pounds of glass for a mirror twenty-seven feet in diameter. That mirror and five more like it will surround a seventh giant mirror on what will be (at least for a while) the world's largest optical telescope: the Giant Magellan Telescope, scheduled to be up and running in northern Chile in about a decade.

The world's most famous mirror, however, is the primary on the beloved Hubble Space Telescope, fashioned from an eight-foot-wide, flat block of glass. It was to be a perfectly polished hyperboloid. Perfectly polished it was: if the mirror were the size of Texas, its biggest bump would be half an inch high. A few hours after the Hubble's launch in April 1990, though, test observations showed that the mirror suffered from serious spherical aberration. Its outer edge turned out to be 0.0001 inch too flat, yet that deviation was enough to make it practically useless for image-taking. Happily for us all, astronauts fixed the problem during the first servicing mission to the Hubble, in December 1993. They gave the telescope a set of corrective lenses—eyeglasses, if you will—that perfectly compensated for the error.

Astrophysicists these days aren't content with just a bucket o' photons. We analyze the properties of detected light—its spectra—because from its spectra we can often extract the source's distance, temperature, chemical composition, motion through space, rotation, polarization, and surrounding magnetic fields. Those are our data. And, just as the wine lover wants a wineglass to be so thin that it is nearly absent as a boundary between lips and wine, the astrophysicist wants extraneous influences to be as absent as possible from the data. Sleepy observers introduce too many extraneous things into the data stream, particularly if their skill at drawing what they've seen is variable. Almost as bad as a sleepy astronomer is the atmosphere's habit of altering a photon's path to a ground-based telescope.

Twentieth-century photography got faster and faster as the decades rolled by, minimizing the problem of recording data accurately. And launching telescopes into space eliminated the problem of atmospheric turbulence.

(Continued on page 66)

When the Shark Bites

Teeth that stab or crush to match their meal

By Adam Summers
Illustrations by Emily S. Damstra

White-spotted bamboo shark (Chiloscyllium plagiosum)

If you could travel back in time some 370 million years and snorkel over shallow reefs in Devonian seas, you would, of course, see alien creatures—the antiarchs (armored fishes), perhaps a long-snouted lungfish, and the spiral shells of ammonites. But your most startling encounter would probably be with an all-too-familiar creature: the ancient shark *Cladoselache.* Its fusiform, or spindle-shaped, body—between three and six feet long—and sharp, multicusped teeth might evoke the same frisson that shark divers so enjoy today.

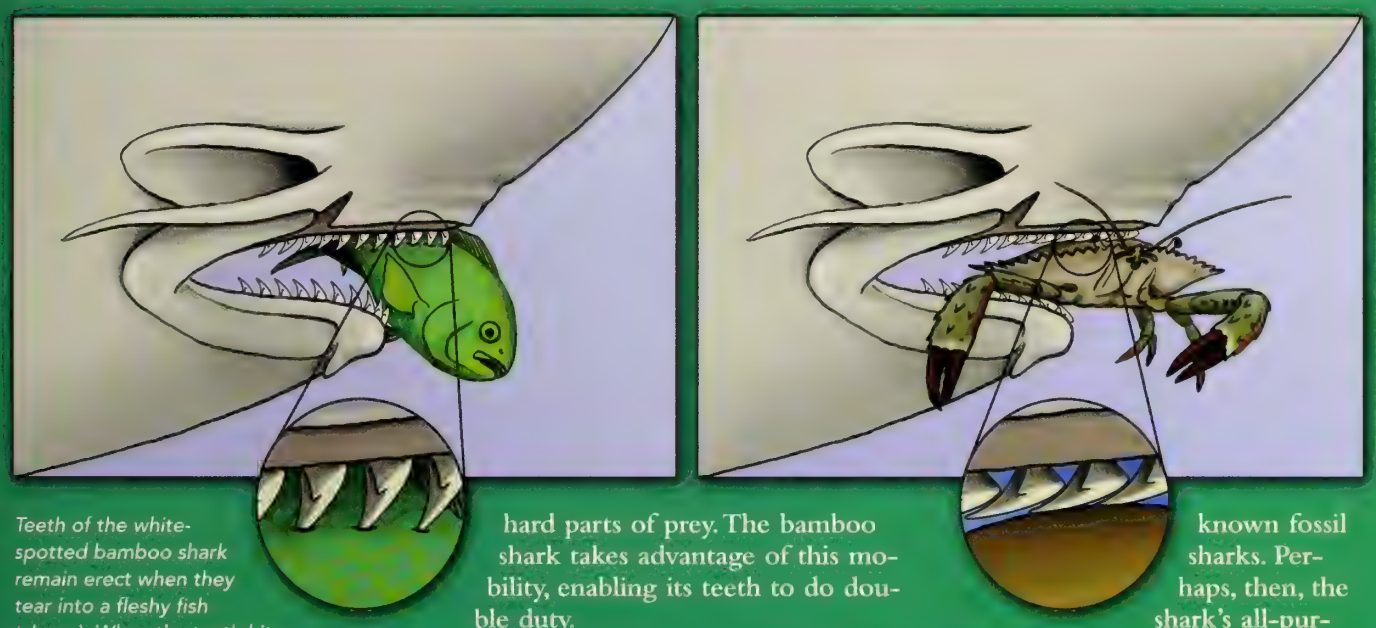
The survival of the shark, in a form relatively unchanged for hundreds of millions of years, attests to the utility of its body plan. Holding evolution at bay for so long requires flexibility. A shrewd recent observation of shark feeding behavior has led to the realization that some species, perhaps including some very ancient ones, can change their teeth as they change their diet.

Most people's impressions of sharks are dominated by *Jaws*-type images of school bus-size creatures cutting through the water with their fearsome mouths agape, exposing their jagged teeth before gnashing down on some hapless creature. Most shark predation—the mako's quick lunge at a tuna or the surreptitious sideways snatch of the sand tiger shark—is far less showy. Some cartilaginous fishes shun fishy prey altogether, preferring creatures that may be harder to process but easier to catch, such as brittle stars, crabs, and sea urchins. The dietary preferences of a species can be inferred by examining its teeth. Triangular teeth, good for cutting and slashing, belong to sharks that eat things larger than their heads; a battery of grasping spikes works well for those wanting to snatch up fish; and a pavement of closely set knobs does the job of crushing hard prey.

The white-spotted bamboo shark *(Chiloscyllium plagiosum)* is a small, spotted shark native to the Indo-Pacific. It is popular in aquariums because it is usually a willing feeder and lays eggs in captivity. Cheryl A.D. Wilga and her graduate student Jason Ramsay, both marine biologists at the University of Rhode Island in Kingston, maintain a small colony of bamboo

sharks for Wilga's research on shark feeding and swimming. One day, instead of feeding the sharks their usual soft diet of squid and fish, Ramsay tossed in a few small New England crabs. To his surprise, the sharks not only eagerly gobbled up the unusual fare but also spat out pieces of shell. Ramsay realized that the sharks had smashed the crabs instead of swallowing them whole.

In the wild, bamboo sharks have a catholic diet that includes small fish as well as a variety of benthic invertebrates such as crab and shrimp. Their teeth seem to reflect their generalist approach to dinner: they are sharp, small, and ideal for gripping and then, through vigorous head shaking, tearing prey into chunks. But sharp teeth seem entirely at odds with the need to crush



Teeth of the white-spotted bamboo shark remain erect when they tear into a fleshy fish (above). When the teeth hit something hard, though (above right), they fold down to form a flat dental plate, suitable for crushing hard-shelled prey.

prey. How could delicate points avoid taking a beating every time the shark chooses a well-armored meal? With a combination of high-speed video, dissections, and experiments that showed the mobility of the teeth relative to the jaws, Ramsay got to the root of the problem.

Shark enthusiasts have long known that sharks have several rows of teeth, all embedded in an elastic dental ligament that, like a conveyor belt, slowly carries the teeth forward from the back of the mouth toward the lip. The frontmost teeth do the biting and chewing; the rows toward the back stay down and out of the way until they reach the front of the mouth. At the same time, though, teeth are constantly being replaced: as the older, front-row teeth break or wear down, they are carried out of the mouth, and the next row of younger teeth moves to the front.

The elasticity of the dental ligament gives shark teeth another unusual property: they can wiggle a bit to fit around bone or skip over hard parts of prey. The bamboo shark takes advantage of this mobility, enabling its teeth to do double duty.

When the bamboo shark's teeth hit soft flesh, the sharp cusps bite in and grasp the prey. A quick shake of the shark's head can then rip the prey in half. But when the shark grabs hard-bodied prey, the sharp points can't make a dent. So instead of letting their edges get dulled on shell, the teeth fold toward the back of the shark's mouth, exposing the front surfaces of the teeth to the prey [*see illustration above*]. The flat tooth face is far better suited to the task of smashing open a crab. Imagine your own teeth tilting backward if you bit a walnut shell, but staying upright on contact with a peach.

The beauty of the system is that no special controls are needed to "decide" whether the prey to be processed is hard or soft. The hardness of the prey itself causes the teeth to change from pointy graspers to lumpy crushers. If the prey is hard, the upright front row folds down onto the next row back, turning the entire dental battery into a crushing plate, similar to the palate of true hard-prey specialists such as the horn shark.

The teeth of the bamboo shark look remarkably similar to those of *Elegestolepis*, one of the oldest known fossil sharks. Perhaps, then, the shark's all-purpose strategy is quite old. But it's not universal—great white sharks have no trouble cutting through surfboards with a static set of dentures, and tiger sharks rip through sea-turtle carapaces like chainsaws through pine.

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NATURAL HISTORY
MARCH 2006

Learning to Find Your Way

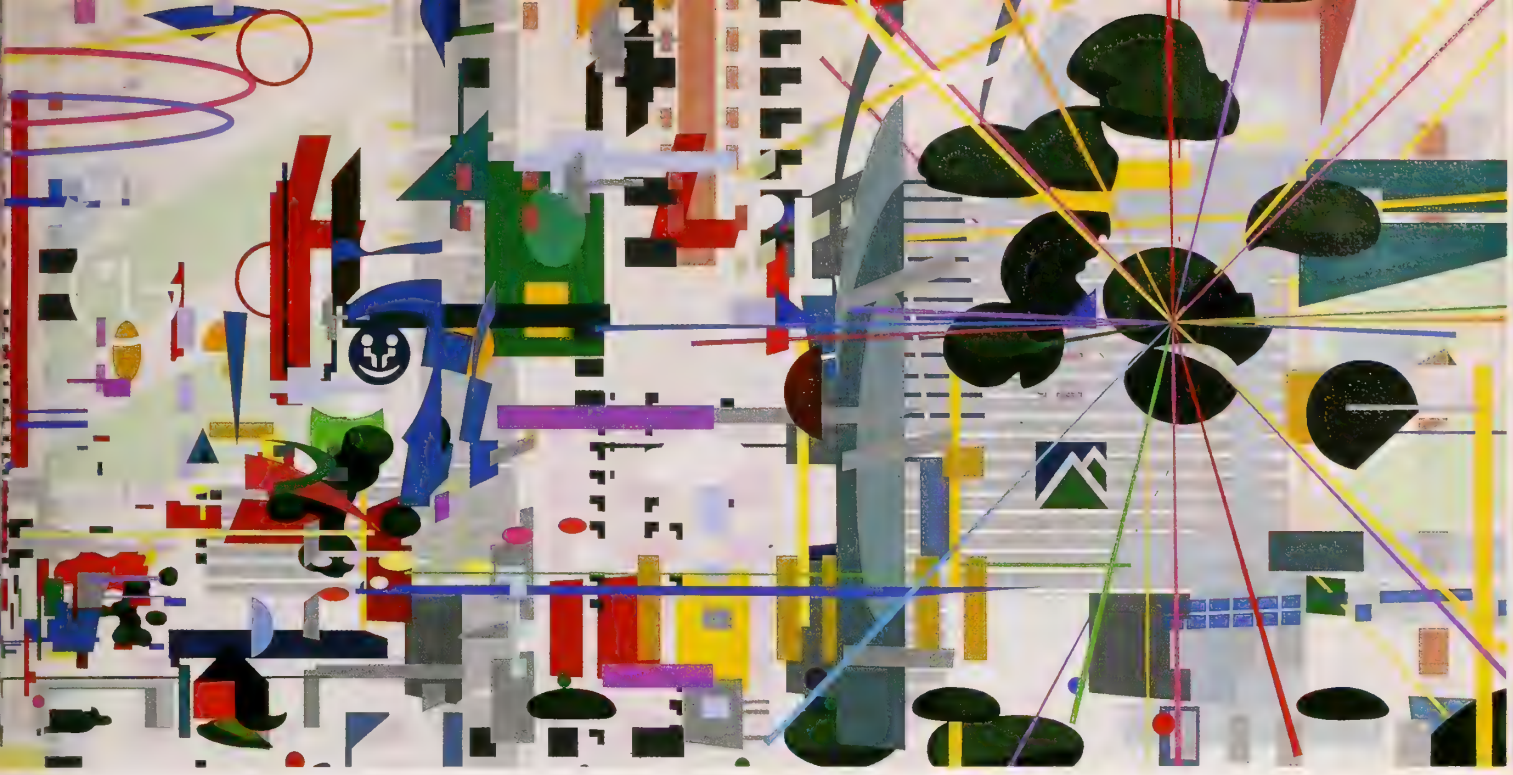
The biochemical pathways underlying spatial memory in the brain are giving up their secrets.

By Eric R. Kandel

For all living creatures, knowledge of the surrounding environment and their position within it is key to behavior and critical to survival. At the simplest level spatial "knowledge" may encompass no more than the ability to orient toward or away from a stimulus. In complex organisms, though, the representation of space is a cognitive process, in which inputs from several senses—sight, hearing, the sensations of motion and posture provided by the inner ear and muscle tension—are bound together. Such binding is a function of the brain. How is it accomplished?

The brain represents information about space in many of its areas and in many different ways. For some purposes the brain represents space with egocentric coordinates, that is, from the point of view of the sensing organism. For example, the brain encodes where a light is relative to the fovea of the retina, or where an odor or touch comes from with respect to the body. For other kinds of behavior the brain encodes the organism's position with respect to the outside world, and the relations of external objects with respect to one another. Such position coordinates, which are centered on the world, are known as allocentric coordinates.

The eighteenth-century German philosopher Immanuel Kant, one of the forefathers of cognitive psychology, argued that the ability to represent space allocentrically is built into the mind. People, in Kant's view, were born with principles



Benjamin Edwards, *The Pusan Experience*, 2002

that ordered experience in space and time, and were prepared to interweave sensations automatically within this framework in specific ways, whether the sensations were elicited by objects, melodies, or tactile experiences.

In the early 1970s, John O'Keefe, a cognitive neuroscientist at University College London, applied this Kantian logic about space to explicit memory—memory that is recalled by deliberate, conscious effort. Explicit memory, which concerns such things as facts and events, people and objects, can be contrasted with implicit memory, such as motor or perceptual skills and conditioned responses, which are accessed and performed unconsciously. O'Keefe argued that many forms of explicit memory are associated with spatial coordinates—that is, we typically remember people and events in a spatial context.

This idea is not new. In 55 B.C., Cicero, the great Roman statesman and orator, described a Greek technique for remembering words. The idea was to picture the rooms of a house in sequence, associate words with each room, and then mentally walk through the rooms in the right order. To this day some actors and others who must memorize and recall information rely on the technique.

O'Keefe was the first to realize that rats have a multisensory representation of extrapersonal space localized in a part of the brain known to be involved in explicit memory storage, called the hippocampus. In 1971 O'Keefe probed how individual neurons, or nerve cells, were activated in the hippocampus of laboratory rats, as the animals walked around in an enclosure. Some neurons, he discovered, are activated when that animal moves to one position, whereas others fire when the animal moves elsewhere. He called these neurons "place cells." On the basis of those findings, it is thought that as an animal explores its surroundings, the brain breaks down the territory into many small, overlapping areas, similar to a mosaic, thereby forming an internal map. The map develops within minutes of the rat's entrance into a new environment. Under optimal circumstances, it lasts weeks or even months.

I began to think about the spatial map in 1992, wondering how it is formed, how it is maintained, and how attention might direct its formation and maintenance. I was struck by the finding of O'Keefe and others that the spatial map of even a simple locale does not form instantaneously. Instead, it forms over a period of between ten and fifteen minutes after the rat enters the new environment. The delay suggested that forming a spatial map is a learning process, in which practice makes perfect. Thus even though the general capability for forming spatial maps that Kant envisioned may be built into the brain, each particular map of a specific environment is not.

When my colleagues and I began studying spatial maps, nothing was known about the molecular details of their formation. But we did have a research advantage. We had spent many years teasing out

some of the biochemical processes whereby neurons alter their responses to stimuli and the connections between neurons are modified as a result of an animal's experience. In other words, we already understood, in principle, what can make learning possible.

We had gained our understanding through the fortuitous choice of a research subject, the marine snail *Aplysia*, an organism with a relatively simple neurological organization. Its brain has only about 20,000 neurons, compared with 100 billion or so in the human brain. Moreover, *Aplysia* neurons are extremely large, some even visible to the naked eye. In that simple animal, we delineated a simple reflex behavior, in which fewer than one hundred nerve cells take part. The reflex could be modified by learning and retained in memory for several weeks. In that way, we were able to pinpoint the cellular and molecular mechanisms that contribute to learning and memory.

One of the rewards of any avenue of scientific investigation is that, as specialized and narrow as it may seem, it can lead to broadly useful insights. Laboratory experiments or field observations that may at first seem to have no practical application can prove helpful or even essential in solving pressing problems. Although it is too soon to say how or when, the accumulating knowledge of the biochemical mechanisms underlying learning and memory may one day help prevent the "normal" memory loss of aging and perhaps even cure Alzheimer's disease and other dreaded neurological conditions associated with learning disabilities.

Spatial learning in a mouse is tested on a circular tabletop rimmed with open holes and one escape tunnel. When a mouse is set out in the open, under bright lights, the animal searches for a hiding place. In early trials, it searches at random until it finds the tunnel. In later trials it methodically checks the holes in some order until the tunnel is found. Finally, the mouse learns where the tunnel is in relation to the walls of the room, and makes a beeline for it. A breed of mice lacking a protein for strengthening the connections between nerve cells—a basis for learning—never makes the transition to the third strategy.

Our studies of neurons in *Aplysia* on a biochemical level made two things clear. First, neurons can adjust their responses to stimuli in the short term, either by becoming more sensitized to an important stimulus (such as one that is harmful) or by becoming habituated to—and therefore ignoring—one that is inconsequential. To make short-term adjustments, the neuron regulates the strength of its connection with other neurons by chemically altering preexisting proteins and increasing or decreasing the efficiency of preexisting synaptic connections.

Second, neurons can adjust their responses over the long term by increasing or decreasing the number of contact points with other neurons. To construct new points of contact, structural proteins are needed; to assemble the proteins, genes that serve as the blueprints for making the proteins have to be turned on, or mobilized, in the nucleus of the neuron.

In the late 1980s, a number of investigators made the first attempts to understand how long-term potentiation, or enhancement, of connections between neurons played a role in spatial memory. At Columbia University, three post-doctoral fellows—Ted Abel, Seth G.N. Grant, and Mark R. Mayford—and I created various lines of genetically modified mice that lacked one or another key protein thought to be involved in long-term potentiation. We then tested the animals' performance on several well-understood spatial tasks.

For example, we placed a mouse in the center of a large, white, well-lighted circular platform, with forty mouse-size holes drilled into the rim [*see illustration at left*]. Mice hate being in light, open spaces, but the platform is too high off the floor for a mouse to escape by leaping off its edge or through a hole. The only escape is through one hole that leads through a tunnel to an enclosed chamber. The mice do get a clue about the way out. The platform is mounted in a small room, each of whose walls is decorated with a different, distinctive marking.

When a normal mouse is first exposed to this experimental condition, it races about in a panic, visiting the holes at random in its search for the way out. After repeated trials it adopts a serial strategy—slightly more efficient than random searching, but not by much—starting at one hole and methodically checking out each one in order until it finds the right one. Neither strategy requires the mouse to have an internal map of the environment stored

in its brain. Finally, the mouse learns to recognize which marked wall is aligned with the target hole, and then it makes a beeline for that hole. Most mice soon learn to use that spatial strategy.

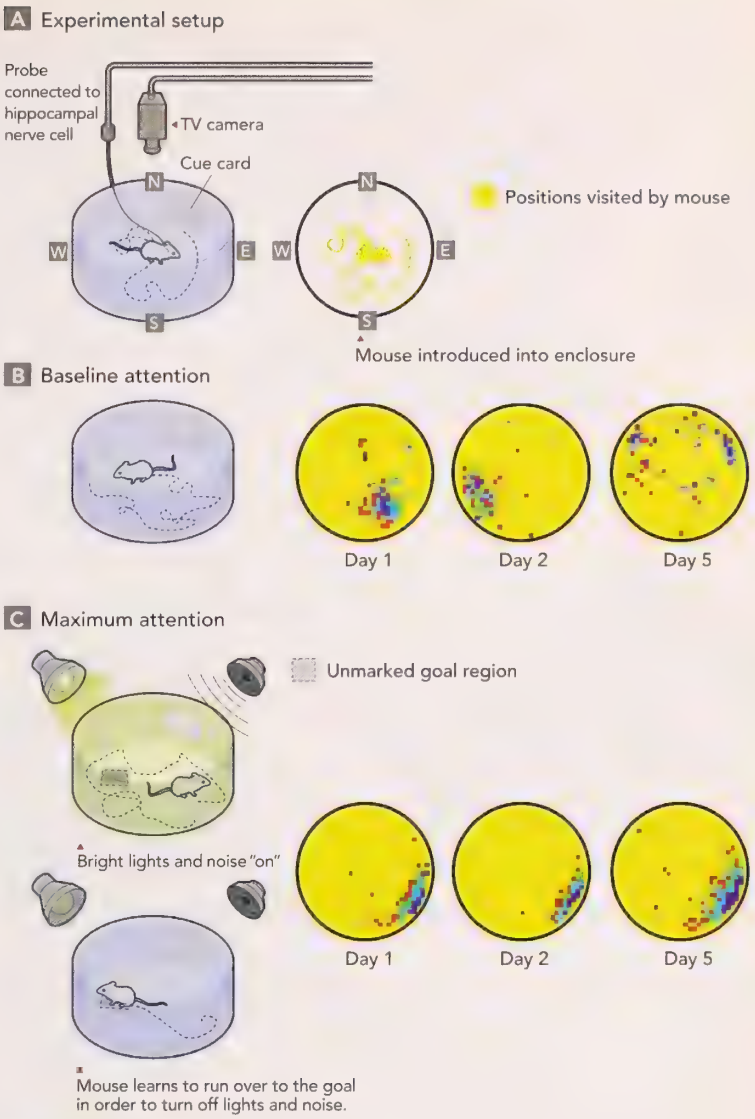
In one of our special breeds of mice, we had inhibited a gene that encodes a protein—protein kinase A. The protein is important for long-term potentiation because it mobilizes genes that, in turn, code for the structure proteins required for building new synaptic connections. Inhibiting the *kinase A* gene compromised the strengthening of synapses in a pathway in the hippocampus. The mutant mice never learned to use the markings on the wall as a guide to the escape hole; they kept searching for it with the simpler but inefficient strategies, in trial after trial.

In later work—in collaboration with the neurobiologist Robert U. Muller of the State University of New York Downstate Medical Center in Brooklyn and his student Alexander Rotenberg—Ted Abel, my student Naveen T. Agnihotri, and I discovered that both protein kinase A and the synthesis of structural proteins are needed for a spatial map to become "fixed" over the long term—so that, for instance, a mouse recalls the same map every time it re-enters a particular space.

In his initial formulation, O'Keefe regarded a cognitive map as merely a kind of a navigational tool, comparable to a compass. Such an internal representation of space would enable an animal to move efficiently in the environment by recognizing directions and landmarks, but it would not endow the animal with any long-term memory of the space. In contrast, our experiments showed that the hippocampus may also serve as a memory store for past responses in encountering those landmarks—thus enabling a normal mouse on the platform to appreciate the value of the spatial landmarks in locating the reward—the escape hole. In this sense it endows an animal with an explicit memory of its space.

My colleagues and I were intrigued by the fact that, despite certain similarities, people's explicit memory of space differs in substantial ways from their implicit memory. For example, hotel guests may remember to proceed to the nearest stairwell if they hear the fire alarm (implicit memory), without remembering that they must pass fifteen rooms before reaching the stairwell (an explicit memory they would possess only if they had consciously counted the doors). Thus, explicit memory requires selective attention for encoding and recall. To examine the relation between neural activity and explicit memory, we decided to study attention.

Selective attention is widely recognized as a



How attention contributes to the formation and stability of spatial memory was studied by the author and his coworkers in laboratory mice. In the experimental setup (a), a probe detects the firing of a "place cell" in the hippocampus of a mouse's brain, while a camera records the mouse's position as it moves about in the enclosure. Visual cues enable the mouse to orient itself within the enclosure. At first the neuron being monitored may fire at random places, but soon it tends to fire only when the mouse visits a certain part of the enclosure. In the diagrams, the colors in the key (above left) indicate the probed cell's rate of firing; areas crossed by the mouse where the cell did not fire are yellow. Data are displayed from three recording sessions for two mice, one simply allowed to explore the empty enclosure (b), the other subjected to noise and bright lights in an identical enclosure (c). In both experiments, the mouse was given thirty minutes on day one to become familiar with the enclosure; it then spent three hours in its home cage before being returned to the enclosure for a thirty-minute recording session. It was then retested for thirty minutes on day two and day five. At a baseline level of attention (b), the firing pattern has shifted by day two and dispersed by day five. In the mouse forced to pay maximum attention to its location (c), the neuron fired only when the mouse visited a highly localized area of the enclosure. This precise mapping was retained for several days.

powerful factor in perception, action, and memory—in the unity of conscious experience. At any given moment, animals are inundated with a vast number of sensory stimuli—far more than the brain can process. Attention acts as a filter, selecting some objects for further processing. As the American psychologist William James noted in his seminal book, *The Principles of Psychology,* in 1890:

> Millions of items . . . are present to my senses which never properly enter into my experience. Why? Because they have no *interest* for me. My experience is what I agree to attend to. . . . Every one knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought.

baseline level of attention, which we called ambient attention. A mouse was given some time to run around in the enclosure, without any distracting stimuli, and the mouse's position and the firing of the cells were recorded simultaneously. In another condition, we engineered things so that as the mouse walked around in its enclosure, bright lights and loud sounds, which the mouse hates, came on periodically and at random. The only way the mouse could turn them off was to run to a small "goal region" on the floor of the enclosure and sit there for a moment. The region itself was unmarked, but the mouse could find it by paying attention to the available visual cues. Mice learn this task very well.

Kentros and I determined that even with ambient attention, the mouse forms a spatial map that

Novel biochemical pathway, postulated by the author and his colleagues, would maintain a new synaptic connection on the tip of a nerve-cell axon. Such new growth strengthens the synaptic communication with another nerve cell and is the basis for the formation of long-term memory. The process begins (a) as a neurotransmitter, in this case serotonin, binds with a receptor molecule on the surface of the axon, both stimulating the new growth and, through a hypothesized intracellular process, triggering prionlike proteins within the axon to convert from a recessive to a dominant shape (b). Dominant prions convert additional recessives to the dominant form (c), which gives rise to a self-perpetuating chain reaction. When paired, the dominant prionlike proteins help regulate the local synthesis of proteins by binding to and activating messenger RNA (mRNA) present in the synaptic region (d). By maintaining local protein synthesis, prionlike proteins maintain the new synapses and prevent them from regressing (e). Because the dominant prionlike proteins are constantly being renewed, the mechanism ensures that the new connection, built as a result of some vital event, is maintained even if it is called upon only infrequently.

Is selective attention required to form and retain a spatial map? Clifford G. Kentros, a postdoctoral fellow, and I exposed mice to experimental conditions that required increasing degrees of spatial attention [*see illustration on preceding page*]. We implanted a probe in the brain of a mouse that could measure the individual firing of as many as four place cells as we tracked the animal's position in a test enclosure. The enclosure was circular, with enough visual cues on its walls for the animal to orient itself and, perhaps, to form a spatial map.

One condition was designed simply to establish a remains stable for an hour or two. Such a map, however, becomes unstable after three to six hours. When a mouse is forced to pay a lot of attention to a new environment, by having to use visual landmarks to learn a spatial task, the spatial map remains stable for days.

So what is the attentional mechanism in the brain? How does it contribute to the strong encoding of information about space and the ready recall of that information after long intervening periods? Michael E. Goldberg and Robert H. Wurtz,

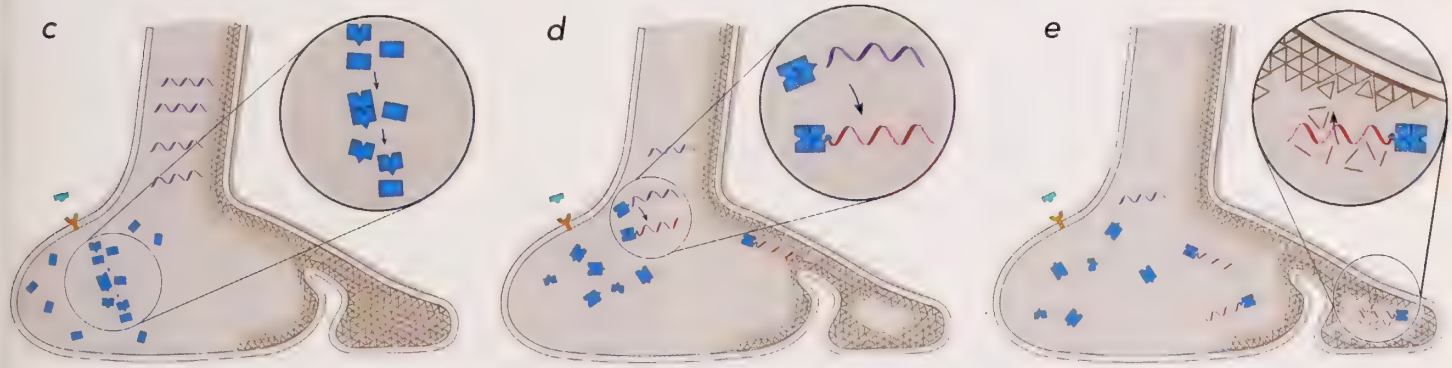
both at the National Eye Institute in Bethesda, Maryland, had already shown that in the visual system, attention enhances the response of neurons to stimuli. One neural pathway that seemed to play a key role in paying attention to a stimulus was mediated by the neurotransmitter dopamine—in other words, the signals transmitted across synapses from one neuron to the next along the pathway were modulated by dopamine. The neurons that make dopamine are clustered in the midbrain; their axons—the long projections from the main body of the nerve cell—send signals to a number of sites in the brain, including the hippocampus.

That suggested an obvious experiment. What would happen to the spatial map of an animal that was paying attention to its surroundings if dopamine was blocked from reaching its hippocampus? My co-workers and I proved just what we had been led to expect: Without dopamine, the spatial map in the mice would not stabilize; the place cells in the mice would not reliably fire as they did when the spatial memory was fixed. Conversely, when we activated dopamine receptors in the hippocampus, the spatial map of an animal became more stable even when the animal was not paying attention.

In *The Principles of Psychology,* James pointed out that there are at least two forms of attention: involuntary and voluntary. Involuntary attention is supported by automatic neural processes, and it is particularly evident in implicit memory. In classical conditioning, for instance, animals learn to associate two stimuli if and only if the conditioned stimulus is salient or surprising. In the textbook case, a bell rings when food is presented to a dog. After several such training cycles, the sound of the bell alone—the conditioned stimulus—is enough to get the dog to salivate. Involuntary attention is activated by a property of the external world—of the stimulus—and it is captured, according to James, by "strange things, moving things, wild animals, bright things, pretty things, metallic things, words, blows, blood."

By contrast, voluntary attention, such as paying attention to where staff members sit in a new office environment, is a feature of explicit memory. It arises from the need to process stimuli that are not automatically salient to the nervous system. James argued that voluntary attention is obviously a conscious process in people; therefore, it is likely to be initiated in the cerebral cortex.

The molecular studies my colleagues and I have conducted in *Aplysia* and mice support James's contention that both forms of attention exist. In both voluntary and involuntary attention, the short-term memory of a salient stimulus is converted to long-term memory through the activation of genes.



In both cases, neurological pathways and chemical transmitters act as modulators, carrying a signal that marks the stimulus for special attention. In response to that signal, genes are turned on and proteins are produced and sent to all the synapses to strengthen the connections between neurons.

For example, *Aplysia* normally withdraws its delicate gill into its mantle cavity if its siphon is touched. The response weakens, through habituation, if the siphon is touched repeatedly but weakly. But if the weak touch is then paired, through conditioning, with a shock to the animal's tail, the weak touch alone will stimulate a brisk response. The shock causes the neurotransmitter serotonin to be released along the neural pathway that carries out the effective motor response for withdrawing the gill. The serotonin triggers protein kinase A, which turns on genes that send structural proteins to the synapses most relevant for quickly withdrawing the gill. Similarly, when a mouse learns the spatial task that switches off obnoxious lights and sounds, we presume that dopamine is released along the neural pathways that represent the mouse's spatial map. The dopamine then triggers the production of protein

kinase A, which "fixes" the memory of the map.

But how do stimuli lead to the release of the neurotransmitters along the "right" neural pathways, marking the stimuli for special attention? In implicit memory storage, exemplified by *Aplysia*'s increased sensitization through conditioning, the attentional signal is called up involuntarily—reflexively—from the bottom up. The sensory neurons, activated by a shock, act directly on the cells that release serotonin. In the mouse's spatial memory, however, the attentional signal is called up in a fundamentally different way. Dopamine appears to be recruited from the top down. The cerebral cortex activates the cells in the midbrain that release dopamine, and dopamine modulates activity in the hippocampus. Nevertheless, in learning to attend, both from the top down and from the bottom up, the underlying molecular mechanisms are similar.

Illusions of size and distance may arise when the brain interprets space on the basis of simple visual cues and learned expectations. If additional cues are taken into account, however, the illusion is quickly replaced by a more robust interpretation. The illusion is part of a temporary exhibit in the Deutches Museum in Munich, Germany.

In 2004 Kausik Si, a postdoctoral fellow in my laboratory, discovered that *Aplysia* carries a novel form of a protein known as CPEB. The novel protein, ApCPEB, is present at all the synapses of the sensory neurons of the gill-withdrawal reflex, where it is activated by serotonin and is required for the growth of new synaptic terminals [*see illustration on preceding two pages*]. Si discovered that one end of ApCPEB has all the characteristics of a prion.

Prions are probably the weirdest proteins known to modern biology. They cause several neurodegenerative diseases, such as mad cow disease in cattle and Creutzfeldt-Jakob disease in people. What is unique about prions is that they can fold into two distinct shapes that function in highly different ways. One shape is dominant, the other recessive. The genes that encode prions give rise to the recessive form. But the recessive form can convert into the dominant form either by chance or as a result of being exposed to the dominant form. For example, the recessive prions in an animal can take on the dominant form if the animal eats food that contains the dominant form.

Most proteins are subject to constant turnover, degraded and destroyed in a few hours. But dominant prions are self-perpetuating, because they can trigger newly minted recessive prions to switch to the dominant form as well, causing a chain reaction. Thus their influence is tenacious.

Soon after Si discovered the prionlike properties of ApCPEB, we postulated that in *Aplysia*'s sensory neurons, serotonin might control the conversion of ApCPEB from its inactive, nonpropagating, recessive form to its active, propagating, dominant form. In other words, the modulatory transmitter required for converting short-term to long-term memory acts by creating dominant ApCPEB protein. And that protein apparently maintains newly grown synaptic connections over long periods, perpetuating memory storage.

If confirmed, the discovery would be the first case in which a physiological signal—serotonin—may be critical in converting one prion form to another. It would be also the first example of a self-propagating prion form that serves a useful physiological function. In all other cases previously studied, the dominant form either causes disease and death by killing nerve cells or, more rarely, is inactive.

After that finding in *Aplysia,* Martin Theis, a postdoctoral fellow in my laboratory, and I began testing the idea that, in much the same way, mouse dopamine controls the conversion of another prionlike protein known as CPEB-3 in the mouse hippocampus. That raises the intriguing possibility—so far only that—that spatial maps may become fixed when an animal's attention triggers the release of dopamine in the hippocampus. That dopamine might then initiate a self-perpetuating state maintained by the dominant form of CPEB-3.

If that idea proves correct, it would open up a new biochemical approach to the stabilization of long-term memory. Eventually, then, new drugs might one day exploit those effects to treat Alzheimer's disease and other disorders of memory. □

This article was adapted from In Search of Memory: The Emergence of a New Science of Mind, *by Eric R. Kandel, which is being published this month by W.W. Norton & Company, Inc.* *Copyright © 2006 by Eric R. Kandel*

Maryland

It's a Natural

Eagle-watch and fossil hunt, camp near the wild ponies of Assateague and crab along Chesapeake Bay, stroll the sandy beaches of Ocean City and hike through areas of major historical significance, all in Maryland, the place for those with a passion for nature. With its remarkably diverse geography—five distinct regions from wetlands to forests—and a wealth of protected lands—27 wildland areas, thousands of acres of state parks, and 13 tidal waterfront parks—Maryland offers unequaled opportunities to bird, bike, boat, canoe, hike, and camp in unspoiled wonder.

Maryland

This state has it all—from seashores to mountains—in diverse geographic regions

THE WESTERN REGION A must-see is the 9,500-acre Dan's Mountain Wildlife Management Area, home to the scarlet tanager, yellow-throated vireo, ovenbird, and many species of songbirds. While you're there, don't miss the spectacular view from Dan's Rock Overlook. For hikers and anglers, Rocky Gap State Park is outstanding. The Park's Lake Habeeb is home to panfish, trophy trout, and large and smallmouth bass, while the Lakeside Trail encircling it offers a scenic and moderate 4.5-mile hike through shoreline, woodlands, and across bridges.

THE CENTRAL REGION Highlights include the Patuxent River Park, 6,700 acres of sandy beaches, marshlands, and wooded bluffs brimming with a great variety of plant and animal life. Birders should visit the Patuxent Research Refuge, a year-round habitat for waterfowl, wading birds, songbirds, woodpeckers, and great blue herons. For hawk and osprey viewing, visit the Hugg-Thomas Wildlife Management Area and the Lower Susquehanna Heritage Center's Conowingo Dam.

THE CAPITAL REGION Comprising Frederick, Montgomery, and Prince George's counties, the Capital Region is not just a great place to stay when you are visiting neighboring Washington, D. C. This area has more than three centuries of history and rolling farmlands as well as cities. Frederick County, in fact, has more farms than any other county in Maryland, with vineyards and covered bridges and Civil War battle sites. Montgomery County also has historical treasures—especially for canal buffs—and the Great Falls on the Potomac River. And for modern history, visit the Goddard Space Flight Center in Prince George's County and learn about the pioneers of space flight.

THE EASTERN SHORE Maryland's Eastern Shore features the Pocomoke Sound Wildlife Management Area and Assateague Island. For eagle sightings, head to Pocomoke Cypress Swamp where flocks of up to 50 bald eagles have been seen. Other Pocomoke residents and visitors include herons, egrets, ducks, ospreys, and barn owls. The mile-long Assateague Island, a national seashore area, is home to famous wild ponies and attracts a host of birds, including brown pelicans, oystercatchers, gulls, and piping plovers.

THE SOUTHERN REGION Located in the Atlantic Coastal Plain—where the waters of the Chesapeake Bay and the Potomac and Patuxent Rivers are never far away—this region boasts historic sites and woods, fields, ponds, beaches, and acres of bald cypress swamps. Fossil hunters should head to 15-million-year-old Calvert Cliffs, where more than 600 species of fossils, including various species of sharks, have been found.

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MARYLAND

WELCOME

*Seize the day off*SM

Damon Hearne

Tom Roland

Top: Parker's Creek, Calvert County, the only undeveloped creek on the Chesapeake's western shore; bottom: wood turtle laying her eggs at Charles County shoreline

Calvert County

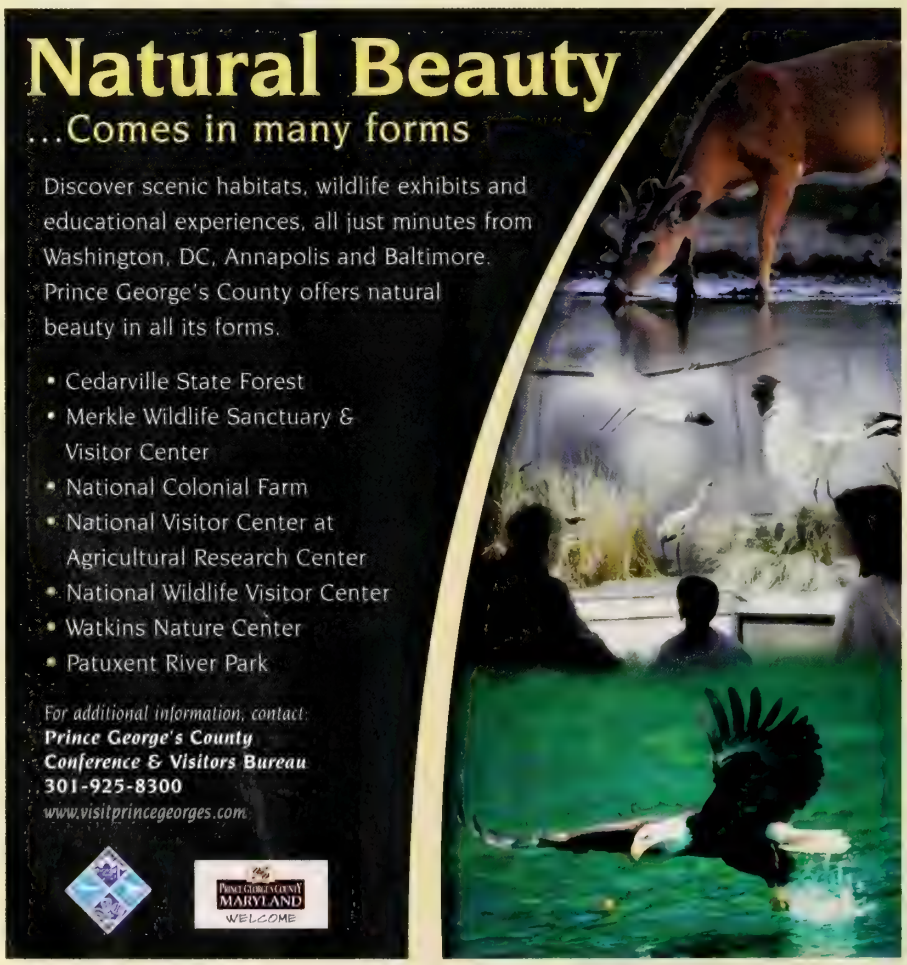
For water-based adventures, visit Calvert County, where the Patuxent River and Chesapeake Bay offer boating and birding. Along the Chesapeake's western shore, head to the American Chestnut Land Trust to hike along the only undeveloped creek and salt marshes in the area. Stop by some of the 20 properties listed on the National Register of Historic Places, visit sites along the Star-Spangled Banner Trail for scenic views and thousands of years of Chesapeake Bay history, and hunt for fossils along the 15-million-year-old Calvert Cliffs. Explore the Chesapeake Beach and North Beach town boardwalks, historical buildings, and beaches. In 2007, several festivals will commemorate the 400th anniversary of Capt. John Smith's travels.

In addition to boasting many national, state, and county park areas, Calvert County is the East Coast's leading supplier of oysters.

Charles County

Small-town charm and big-time opportunities to experience nature exist less than an hour from Washington, D.C. Home to more than 321 species of birds, including the second largest bald eagle population in Maryland, 150 miles of spectacular shoreline, and numerous Civil War sites, Charles County lets both nature lovers and history buffs explore their passions.

An abundance of undeveloped areas, including "green tree" reservoirs, which are deliberately flooded forest areas, creates a haven for wildlife. Along the Mattawomen Creek, birders can look for the barred owl, multi-colored songbirds, and the wood ducks that favor this habitat. In the Cedarville State Forest, the original winter camping ground of the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Piscataway Indians, visit the only warm-water fish hatchery and hike 19.5 miles of loblolly pines–filled trails. Other places to visit include the Nanjemoy Creek Great Blue Heron Sanctuary, where 2,500 herons annually reappear to mate and nest, and Indian Head's Chicamuxen Wildlife Management Area, whose 381 acres of protected marshlands and interior forests offer almost daily opportunities for eagle sightings.

Originally established as a refuge for migrating birds, Blackwater National Wildlife Refuge in Dorchester County is now home to three endangered or threatened species: the bald eagle, the Delmarva fox squirrel, and the peregrine falcon.

Tom Roland

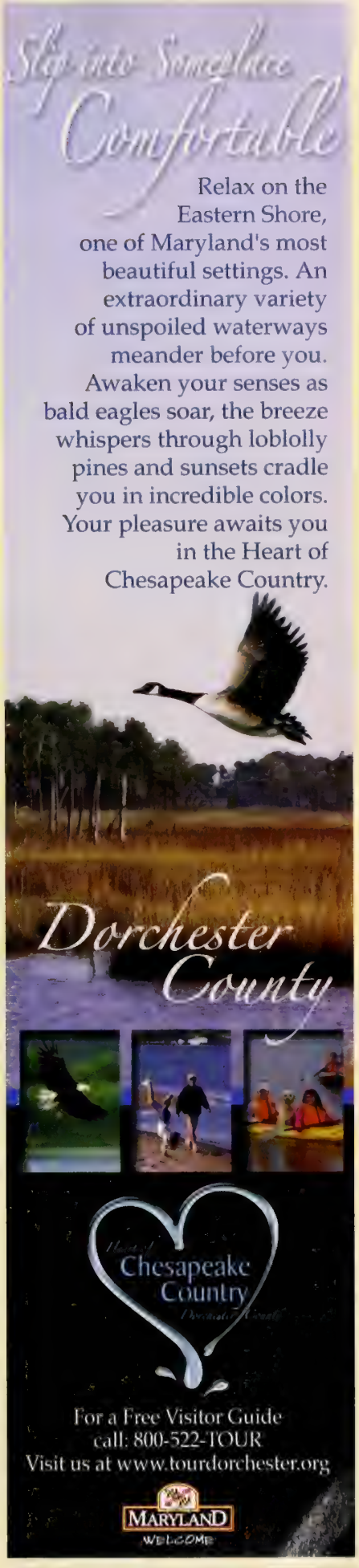
Eagle views are common in Charles County, especially during the mating season in March

Canada geese along the Atlantic Flyway, Dorchester County

Dorchester County

Known as one of the top ten birding sites in the country, Dorchester County is rich in both history and natural beauty. Dorchester County's 1,700 miles of Chesapeake Bay shoreline offer wetlands, wildlife habitats, rural lands, and the renowned Blackwater National Wildlife Refuge to explore.

The refuge is one of the chief wintering areas for Canada geese using the Atlantic Flyway. Geese number approximately 35,000 and ducks exceed 15,000 at the peak of fall migration, usually in November. Trails for both hiking and driving, such as the Marsh Edge Trail and Woods Trail, allow visitors to experience a variety of habitats and wildlife. The refuge's 26,000 acres include rich tidal marshes, freshwater ponds, mixed evergreen and deciduous forests, and small amounts of cropland and managed impoundments that are seasonally flooded for waterfowl use. Also of interest are the Fishing Bay Wildlife Area and Elliott Island, known as Maryland's Everglades. Here you can see osprey, black ducks, herons and marsh wrens, terns and northern harriers.

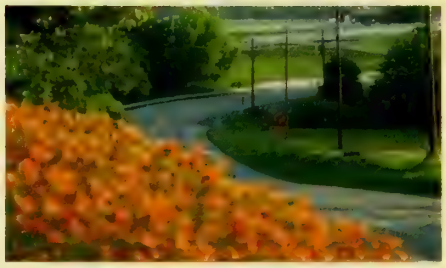


Frederick County

The Catoctin Mountains and Potomac River are just a few of the natural wonders of Frederick County. Head to the Catoctin Mountain National Park for spectacular scenic overlooks along the mountain ridge, plus drives and hiking trails leading through forests, orchards, and more. Visit the park's preserve and zoo for an intimate look at hundreds of exotic animals, as well as indigenous wildlife, wildflowers, and historic buildings.

Other area attractions include Cunningham Falls State Park, with its eponymous 78-foot cascading waterfall, and Gambrill State Park, for hiking, biking, and horse trails with stunning views of the surrounding area. For a look at a local natural phenomenon, visit Fountain Rock Nature Center, a 22.5-acre park featuring a spring that generates 3.25 million gallons of water per day.

Photos: Bernadette Van Pelt

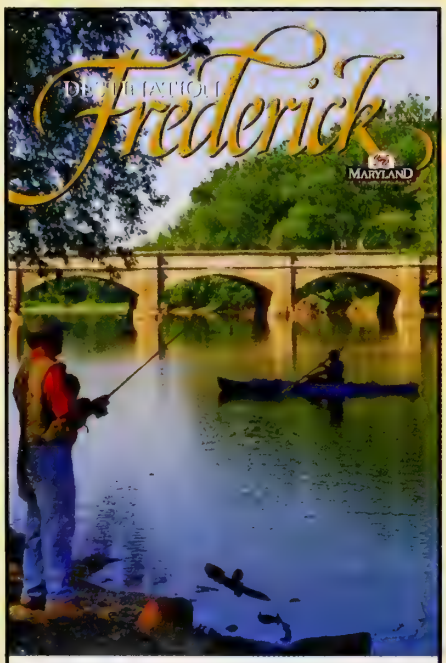


Top: Chestertown, Kent's county seat, celebrates its 300th birthday in 2006; below: the County of Kent, less than two hours from Philadelphia and Washington, is home to a portion of Maryland's first National Scenic Byway.

Kent County

The County of Kent, a scenic peninsula on the Chesapeake Bay, claims a portion of the first National Scenic Byway in Maryland. This destination hosts historic waterfront towns, stretches of rolling farmland, dramatic sunsets, scenic beauty, and rich heritage. Enjoy art galleries, two theaters, specialty shops, five museums, terrific restaurants, farmer's markets, beaches, boating, fishing, and paddling.

Chestertown, the county seat, celebrates its 300th birthday with events throughout 2006 (details at www.kentcounty.com). Incorporated in 1706, this riverfront town boasts the second largest collection of eighteenth-century structures in Maryland and a tree-lined, red-bricked historic downtown. The town of Betterton will be turning 100 years old in 2006. Helping celebrate are sister towns Rock Hall, Galena, and Millington.



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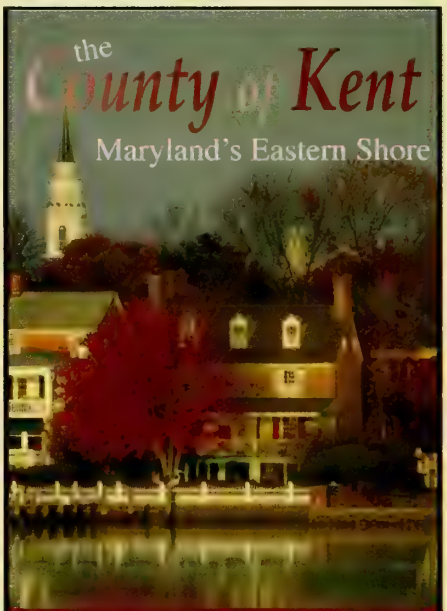

Chestertown, Rock Hall, Galena
Betterton, Millington

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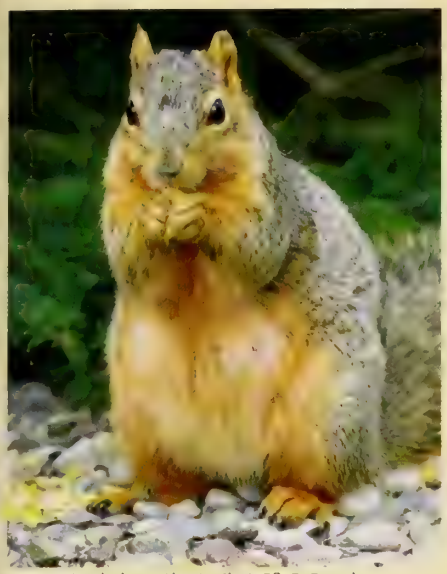
CHARLES COUNTY MARYLAND WELCOME



Fox squirrel along the trail at C&O Canal

Montgomery County

To see bald eagles, songbirds, and salamanders, visit the Chesapeake & Ohio National Historical Park of Montgomery County. A highlight of the county, the 19,236-acre park offers a chance to hike, canoe, bike, and horseback ride within important and varied habitats, both aquatic and terrestrial. Within the park, the 185-mile C&O Canal offers a glimpse into both history and nature. Built during the Canal era as a transportation route from the Chesapeake Bay, the C&O Canal retains hundreds of original structures, including locks, lock houses, and aqueducts. The Canal also provides habitats for animals during breeding, migration, and throughout the year. Its diverse areas, including wetlands, streams, rivers, springs and seeps, and open water, are habitats to such animals as frogs, toads, salamanders, fish, freshwater mussels, beaver, and muskrat.

The spectacular view of the Potomac River Valley, seen from the Canal's hiking path, is not to be missed. In the rest of the park, visit the deciduous forests whose open fields and rocky outcrops support deer, songbirds, red and gray foxes, raccoons, gray and fox squirrels, and black bears. For gardeners, be sure to visit the award-winning Brookside Gardens with its 50-acre public display garden located within Wheaton Regional Park.

With more than 23,000 acres of parkland, Prince George's County offers a unique combination of outdoor recreation and natural resources.

Prince George's County

History, nature, and culture are seamlessly woven throughout Prince George's County. As you birdwatch in Colman Manor's Dueling Creek you are standing at the site of more than 50 duels fought during the first half of the nineteenth century. As you explore the relics on Mount Calvert representing 8,000 years of Native American, Euro-American, and African-American history, you are also witnessing nature at its wildest.

For wetland habitat viewing, head to the 60-acre Suitland Bog to experience the last undisturbed coastal plain bog, which is home to a variety of carnivorous, rare, and threatened plants. The 200-acre Cheltenham Wetlands Park offers a wetland nature study trail with overlooks for viewing various species of birds, insects, amphibians, and fish. Here you can also see other species including deer, muskrats, bluebirds, hawks, and frogs in their natural environment.

Other places of interest include Lake Artemesia Natural Area, with its 38-acre lake, aquatic garden, fishing, and more than two miles of hiking trails; Cosca Regional Park's Clearwater Nature Center, with its interesting environmental displays, indoor pond, lapidary laboratory, and seasonal butterfly gardens; and the Patuxent River Park with its 6,000 acres of natural area parklands where you can hike, canoe, birdwatch, or view the abundant wildlife. There is a park for everyone in this county!

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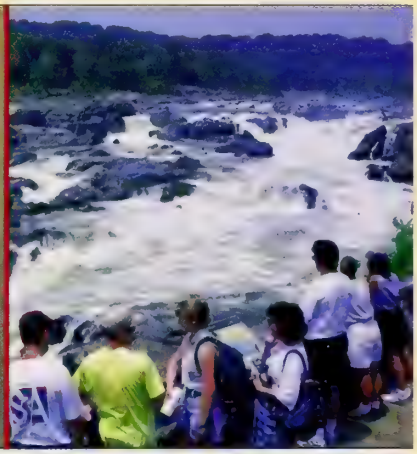

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Along Maryland's Eastern Shore, Talbot County accounts for 600 miles of tidal shoreline, more than any other county in the country. Its many natural resources have attracted Native Americans, European settlers, and now maritime nature lovers. A system of greenways, stretching from Tilghman Island in the west to Cordova in the east, provides sailors, sport fishers, and birders many opportunities to experience nature in its unspoiled beauty.

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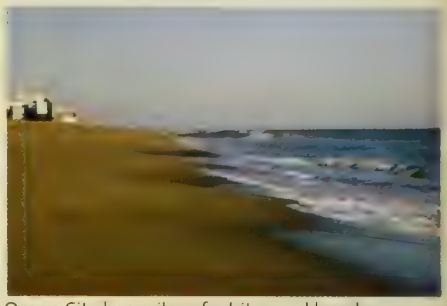
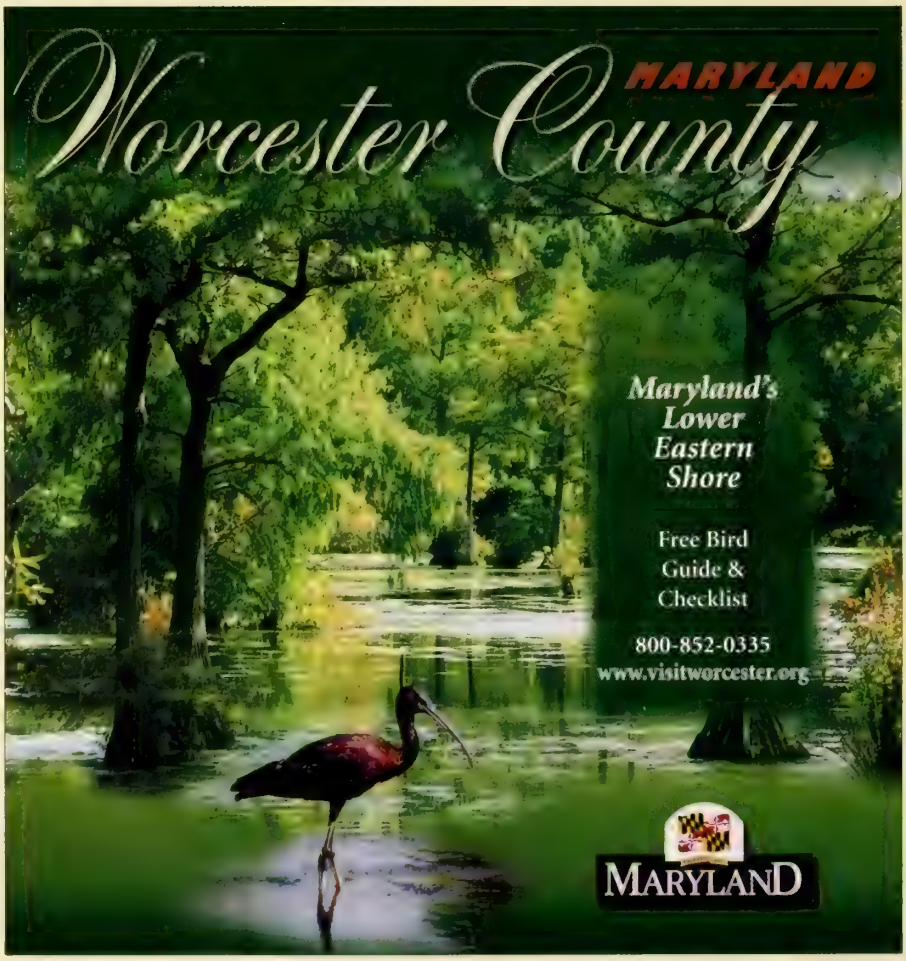
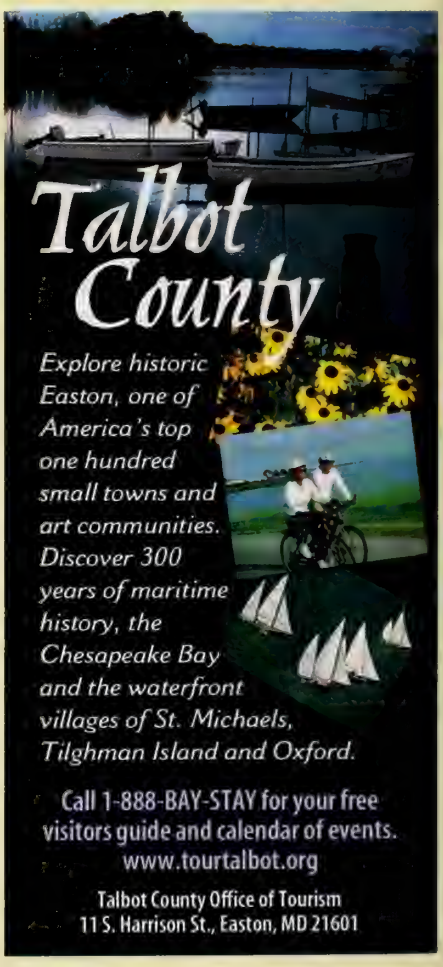


Ocean City has miles of white sand beaches

Worcester County

Home to two state parks, a national park, and a state-designated scenic river, Worcester County is where birders can spot more species than in any other county in the state, where hikers can enjoy the unspoiled beauty of the regional greenway system and anglers can try for shark and tuna. On Assateague Island, a natural barrier island, visitors can not only see the wild ponies in their natural habitat but also camp on the beach nearby.





The scenic Pocomoke River runs through Worcester County

When spring comes to the Pocomoke State Forest so do the birds: the brown-headed nuthatch, the white-eyed vireo, Acadian flycatcher, Eastern wood pewee, and the wormeating and black-and-white warblers, plus shorebirds pass by in May. The Pocomoke River, which flows through cypress swamps, is teeming with wildlife: 27 species of mammals, 29 of reptiles, 14 amphibians, and 172 species of birds. And of course, Ocean City, with its 10 miles of white sand beaches and boardwalk filled with shops and amusements parks, offers a different kind of natural history.

Maryland is a natural for your next vacation. For a free travel kit, please visit www.visitmaryland.org/mag.

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Captain John Smith

For the ultimate field guide to the Chesapeake Bay area, pick up *Landfall Along the Chesapeake: In the Wake of Captain John Smith*, by Susan Schmidt. This evocative and informative book follows Schmidt as she retraces John Smith's 1608 voyage on the Chesapeake Bay. As she circles the Bay counterclockwise from Jamestown, she explores Smith's encounters with Native Americans and the Bay's ecological changes over the past four hundred years. On each river and creek, she quotes Smith's journals on matching wits with Powhatan, meeting Pocahontas, surviving thunderstorms, ambush, and a stingray's barb. Anchored on wild creeks, Schmidt observes swans and dragonflies, lightning and sunsets; in port she interviews colorful characters and working watermen about blue crabs and oysters.

Superbly illustrated and clearly written, this acclaimed guide describes more than two thousand plants and animals and their habitats, from diamondback terrapins to blue crabs to hornshell snails. "Handsome, generously illustrated," said the *Washington Post Book World*; "a story book, a field guide and a reference work," raves the *Baltimore Sun*; and "the best-written and best-illustrated guide ever about a North American tidal estuary," says *Whole Earth Review*. *Landfall Along the Chesapeake: In the Wake of Captain John Smith* is a must-read for naturalists, conservationists, and boaters alike.

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Smart Weapons

With an arsenal of quills and chemicals, the porcupine mounts one of nature's most robust defenses against predators.

By Uldis Roze

It is a clear, midsummer midnight in the Catskill Mountains of upstate New York, and I'm trying to capture Loretta, an adult female porcupine. In preparation, I'm wearing heavy vinyl gloves to protect myself from Loretta's bristling armor of quills. I plan to scoop her up and place her temporarily into a snug, three-gallon picnic cooler, then make some measurements and observations for my research on the social structure of her species.

But Loretta has other plans. She strikes my glove hard with her tail. The thick vinyl stops most of the quills, but many sharp points still pierce the fabric and dig painfully into my fingers and palm. My hand feels useless from the pain. Round one goes to Loretta.

Contact with a porcupine's tail leaves quills embedded in, and even piercing through, a heavy vinyl glove. Removing a well-rooted quill can take more than ten pounds of force.

Porcupines, for the most part, have a sweet and trusting disposition that comes only to those who have little reason to be afraid. Of course, quills are the animal's best-known defense. Each quill is between one-half and four inches long, with one-way barbs for burrowing into the victim's body and an antibiotic coating to limit the damage if the porcupine quills itself. The quills number in the tens of thousands and cover every inch of its body, with the exception of its face, belly, and the undersides of its limbs and tail.

But there is more to a sense of security than merely possessing an advanced weapon. If your enemies attack you, you may win in the end, but you still risk being injured in the process. To avoid a fight at all, you have to deter an attack with warnings. Your enemies have to realize that you possess your weapon, and be reminded, in no uncertain terms, that if you're attacked, you will use it. Thus porcupines broadcast a distinct, pungent warning odor when their quills are erected. Furthermore, the quills contain a fluorescent material that brightens the quills at night, when the porcupine is most likely to meet predators. Those evolutionary adaptations ensure a safe infancy for porcupine offspring and relatively long life for the adult—one radio-tagged female lived in my Catskills study area for twenty-one years.

I strip off the quill-perforated glove with my teeth, and finish the capture barehanded. I clap the cooler's lid over Loretta to immobilize her dangerous tail and lower back. Little drops of blood speckle my hand and fingers. But I have been lucky—none of the quill tips have broken off to travel deeper into my body. I weigh my prickly friend, note that she is lactating, and then let her go. She moves off briskly to her baby in the woods.

But Loretta has left something of herself behind—a small forest of quills embedded in my rubberized glove. To use the glove again, I must pull out all the quills. But when I start pulling, I am struck by how firmly the quills are anchored in the glove. So instead of just finishing the job with fingers or long-nose pliers, I decide to measure how much force is needed to withdraw each quill.

I have an accurate spring balance, with a maximum capacity of 10.5 ounces. All I have to do is attach an alligator clip to the spring and grip each quill with the clip while I give a pull. I tally eighty-four quills, and I measure 6.7 ounces of force per quill, on average, to extract each one of them. In fact, my

result is a gross underestimate. Twenty of the quills in my glove take more pull than the balance can register. In a later experiment I discover the extraction tension for individual, well-rooted quills can be twenty-five times higher than my first calculation suggests, or in excess of ten pounds apiece!

Even if the extraction force were "only" 6.7 ounces per quill, extracting all eighty-four quills at once would take a pull of more than thirty-five pounds. That is well above Loretta's body weight—thirteen pounds—and far more force than she could conceivably exert on her own, especially considering that porcupines have relatively little muscle compared with other mammals.

So how did Loretta separate herself from the glove? Not by pulling her quills out of it. Instead, she shed them from her skin. Does that solve the paradox? It might if eighty-four quills could be removed from Loretta's skin with a force roughly equal to her weight—about two and a half ounces per quill. I do the obvious experiment. I anesthetize Loretta and seven other porcupines with a quick-acting drug, and measure the withdrawal tension of a few of the animals' quills. The average quill-withdrawal tension is 3.2 ounces per quill, still too much for a little animal to disengage quickly from her target. In other words, when Loretta struck my glove, she should have remained stuck to it, tied

Picnic cooler is a handy, low-tech tool for capturing and temporarily restraining a porcupine for scientific study. The animal in the photograph is a female the author named Loretta. Well-defended by their quills, porcupines have a sweet and trusting temperament.

down like a bristly Gulliver by multiple tiny bonds.

The fact that Loretta was able to break her eighty-four connections in a flash suggests something is wrong with my analysis. David M. Chapman, a histologist at Lakehead University in Thunder Bay, Ontario, who has studied porcupine skin and quill follicles microscopically, offers an alternate explanation: the force needed to separate a quill follicle from the skin of the porcupine may drop after the quill has been driven into an adversary. Consider one of the quills stuck in my rubberized glove. When the quill tip struck the glove, an equal and opposite reactive force drove the quill root deeper into the skin of the porcupine. The inward push was probably violent enough to break some of the attachments between the base of the quill and its surrounding tissues. As a result, less force would have been needed to separate the quill from the porcupine's body.

How to test the hypothesis? Pulling quills from a porcupine on the defensive is difficult and dangerous business. Chapman suggests an elegant way around the problem. Strike the back of an aroused porcupine with a block of something light and penetrable, such as cork or styrofoam, and leave it in place. Then anesthetize the animal, separate the block from the animal by cutting off the tips of the quills embedded in the block, and measure the force needed to pull the quills with the cut-off tips out of the animal's skin.

I try the technique on a female I have named Heart. The results are clear-cut: it takes, on average, only 1.9 ounces per quill to pull the six struck quills out of the animal. By contrast, it takes 3.4 ounces per quill to pull six undisturbed quills from the same area on the porcupine. Experiments with other porcupines confirm that the tension required to extract a quill from a porcupine is reduced by about 40 percent if the quill is first driven into the porcupine's body. That's exactly what would happen after a tail slap or other violent contact with an antagonist.

Chapman has photomicrographs that show enough detail to figure out how the trick is done. Beneath the surface of the porcupine's skin, each quill is surrounded by a spool-like structure made up of dense connective tissue [*see illustration on opposite page*]. This "guard spool" lies just below the shoulders of the quill shaft, which flare outward sharply and so prevent the quill from being driven deep enough into the porcupine to cause the animal injury.

When the porcupine is relaxed, the guard spools move freely: if you strike the quills of an anesthetized porcupine, the spools just glide in with the impact, and the quills remain anchored in the animal as firmly as ever. (That property guarantees, for instance, that a sleeping porcupine doesn't lose its quills if they accidentally press against a tree trunk.) When a porcupine is provoked, however, and its quills are erect, the guard spools are held in place by taut connective tissue in the skin. If a strong downward force is applied to the quill's shaft, it drives the quill root deeper into the porcupine and shears it from the

Threatened by a predator, a porcupine (above) hunkers down with its head away from the danger, preparing to use a slap of its tail to thrust sharp-pointed quills into its enemy (dog at right). To avoid a full-blown confrontation, the porcupine also emits a highly distinctive and pungent odor, warning its foe to back off.

surrounding tissue. The animal can then readily shed the quill and escape its injured adversary.

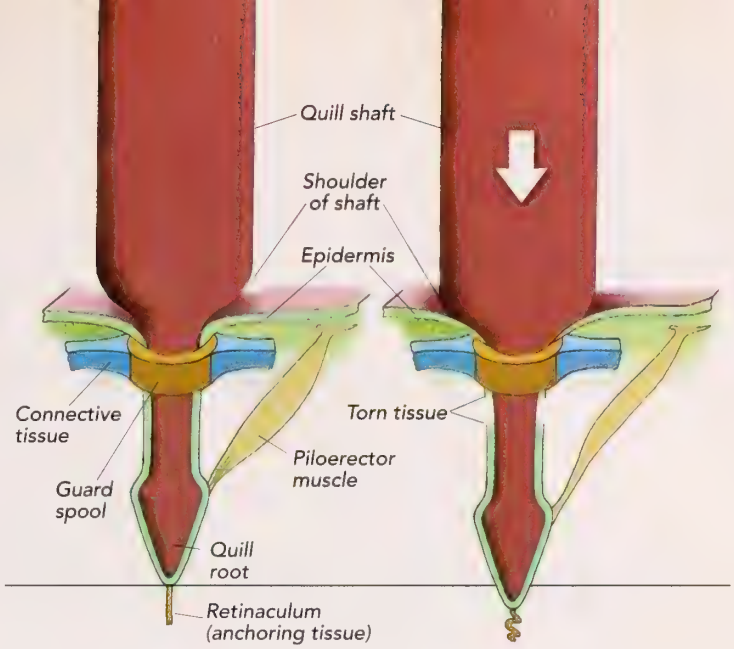
But battles with predators do carry the risk of injury to the porcupine. I once examined the skull of a porcupine at the University of Wisconsin Zoological Museum in Madison that bore silent witness to a violent encounter. The skull dates from the 1890s, when wolves and wolverines shared the porcupine's habitat. The skull was indented on top and partly flattened by the jackhammer impact of a canine's crunching down. Subsequent healing shows that the porcupine survived, yet the margin between life and death must have been thin.

To avoid such battles, the porcupine issues warnings, and its primary warning signal is olfactory. As a porcupine waits for an attack, quills erect, it pours out a wave of pungent odor to signal that its foe would do better to back off.

The odor is generated by a patch of skin called the rosette, on the porcupine's lower back. Specialized quills growing out of the rosette help broadcast the smell. Biologists have long noted modified hairs that disseminate odors in other mammals: black-tailed deer, the crested rat of East Africa, several bat species, and others. Such hairs are called osmetrichia, and they differ from ordinary hairs in having increased surface area and in their ability to stand erect when the animal is on alert. The greater surface area holds more odorant molecules, and the erectability helps disseminate the molecules into the air. In porcupines, the barb-covered section of the quills in the rosette area is longer than it is on quills of the upper back, and the rosette barbs themselves have the greater overlap. Both effects increase the surface area of the rosette quills.

Just as the swat by Loretta got me hooked on how quills exit the porcupine, another nighttime encounter propelled me on the path to identifying the porcupine's warning odor. Passing under an apple tree in the dark, I sensed an alarmed porcupine on a branch above me simply by its wave of smell. That warning smell has a penetrating quality somewhat similar to the smell of goat or perhaps an exotic cheese.

I asked David C. Locke, a chemist at Queens College in New York City, whether he could help me identify the warning-smell molecule. David operates a gas chromatograph-mass spectrometer (GC-MS). The gas chromatograph sorts a gas mixture into its various components, according to the rate at which each component gas leaves the system. Then the mass spectrometer helps identify each component by its molecular mass and fragmentation pattern.



Root of a porcupine quill (left) is held erect and tightly in place by a spool of connective tissue and a contracted piloerector muscle when the porcupine senses imminent danger. If the quill strikes another object, it is driven back into the porcupine's body and through the immobilized spool (right), shearing the attachment of the root to surrounding tissue. The quill can then be readily detached from the porcupine.

Before the instrument can work its magic, however, a smell must be captured. A portable air pump draws the odor through a cartridge that contains charcoal, silica gel, or some other odor-absorbing compound, until the compound is saturated. The odor is released, or "desorbed," by heating or adding a solvent, and passed through the GC-MS.

I set to work capturing a porcupine, securing it in a picnic cooler, then sucking air through the cooler and through a cartridge. David advised drawing the air for at least two hours to saturate the cartridge, but that's much longer than I usually keep my guests. Besides, this porcupine has other ideas. After a quarter hour, it grows bored with its tight, dark enclosure and begins chewing the plastic walls of the cooler to get out. I hurriedly release the animal, then continue to pump air through the damaged cooler, which reeks of angry porcupine.

David desorbs the cartridge and runs it through the GC-MS. Now comes the first reality check. What the printout reveals about the cooler's environment is not what is perceived by the human nose. Instead of the smell of angry porcupine, the GC-MS detects a jumble of thirty compounds. The biggest component is naphthalene—the active ingredient in mothballs. Belatedly, I remember that in the back room of the cabin, where I have set up the cooler and air pump, there is a mothball-filled clothes closet. Another major component is identified as a plasticizer—released when the porcupine started demolishing the plastic lining of

the cooler. The technique will have to be rethought.

At this point, I realize that a good part of the residual porcupine smell is coming from quills scattered on the bottom of the cooler, not from the cooler walls. That makes my job a lot simpler. I won't need to collect odor from a living, thrashing porcupine—freshly pulled quills will do just fine.

David assigns the problem of structure determination to a talented graduate student, Guang Li, who sets competently to work. We eliminate the problem of room-air contaminants by filtering the incoming air. Guang improves the discrimination of the system until eighty-nine compounds in the porcupine odor can be chemically separated. The active principle of porcupine warning odor must be lurking somewhere among the eighty-nine peaks of Guang's chromatogram. But which one?

Guang sets out to trap the porcupine odor in a different way. Solvents such as water or alcohol vary in polarity, or the amount by which negative electric charge is concentrated on one side of the solvent molecule and positive charge on the other. Guang knows that solvents of differing polarity extract different components of a mixture, so he washes a cartridge containing porcupine odor through three solvents of increasing polarity.

It's an eerie experience, smelling porcupine in a bottle—one has a sense of imprisoned wildness.

But Guang has never encountered a porcupine and doesn't know what one smells like, so he asks me to smell the three extracts. The first vial is odorless. The second vial has an odor, but it is not porcupine-like. But the third vial, collected with the strongest solvent, strikes the nose with a strong porcupine smell. It is an eerie experience, smelling porcupine in a bottle—one has a sense of imprisoned wildness, like the unfortunate genie of Arabian folk tales. On chromatography, the third vial sorts into just three principal components. Two of them are common compounds that can be eliminated at once. The third is an unusual compound called delta-decalactone, a ring-shaped molecule with ten carbon atoms, two oxygens, and eighteen hydrogens.

To confirm this molecule is the active element of the warning odor, Guang sets up an elegant experiment. He sends the contents of an odor cartridge impregnated with porcupine odor through a gas chromatograph. Then he splits the instrument's output—the usual eighty-nine components—into two parts. One part goes to a strip-chart recorder, which generates the familiar pattern of peaks and valleys of porcupine odor. The other part goes to a biological detector—the human nose. Locke, Guang, and I all donate our noses for detector duty. (By this time Guang has accompanied me on a Catskill visit to catch and smell a porcupine, and so recognizes its unique odor.) We take turns going off nose duty so that one of us can annotate the strip-chart recorder.

Then it happens. "Porcupine!" I cry out, and Guang marks the spot on the strip chart. The odor builds, incredibly strong because the vapors are heated, with the signature of pure porcupine. Then it ends, and there is olfactory silence. The peak that Guang has marked on the strip chart is delta-decalactone.

Only one small step is left: to cross-check the odor against commercial delta-decalactone. The small, brown bottle arrives. I unscrew the cap and sniff. Oh, no, there is a strong smell of coconut, not the expected porcupine. Something is terribly wrong with our hypothesis.

In the excitement of assigning a name to the porcupine odor, we had forgotten that delta-decalactone is the name for two closely related compounds. The two are optical enantiomers—they differ from each other in the way two mirror images differ, thanks to the asymmetrical arrangement of other atoms around a carbon atom. Chemists call one of the pair the R-enantiomer, the other the S-enantiomer.

The commercial sample I had sniffed was a fifty-fifty mix of the two enantiomers. If there is to be any hope for our hypothesis, only one of the two compounds smells like coconut, the other like porcupine, and the coconut smell overwhelms the porcupine. At least there is a well-known chemical precedent for different-smelling enantiomers. Carvone, for instance, another ten-carbon molecule, also exists in two enantiomeric forms, each with its own distinguishing odor: R-carvone is the pungent fragrance of spearmint, whereas S-carvone gives caraway its characteristic aroma.

So which of the two delta-decalactones has the smell of porcupine? To answer the question, we need two things: a specialized gas-chromatography column, known as a chiral column, that can separate optical enantiomers from each other, and a sample of authentic R- or S-delta-decalactone. Locke piques the interest of an arm of Sigma-Aldrich Co., a technology firm in St. Louis, Missouri, in the project, and the company donates three of its Supelco chiral columns to the laboratory. Guang investigates chemical databases to find a chemist who has worked with delta-decalactones, and we finally obtain a tiny

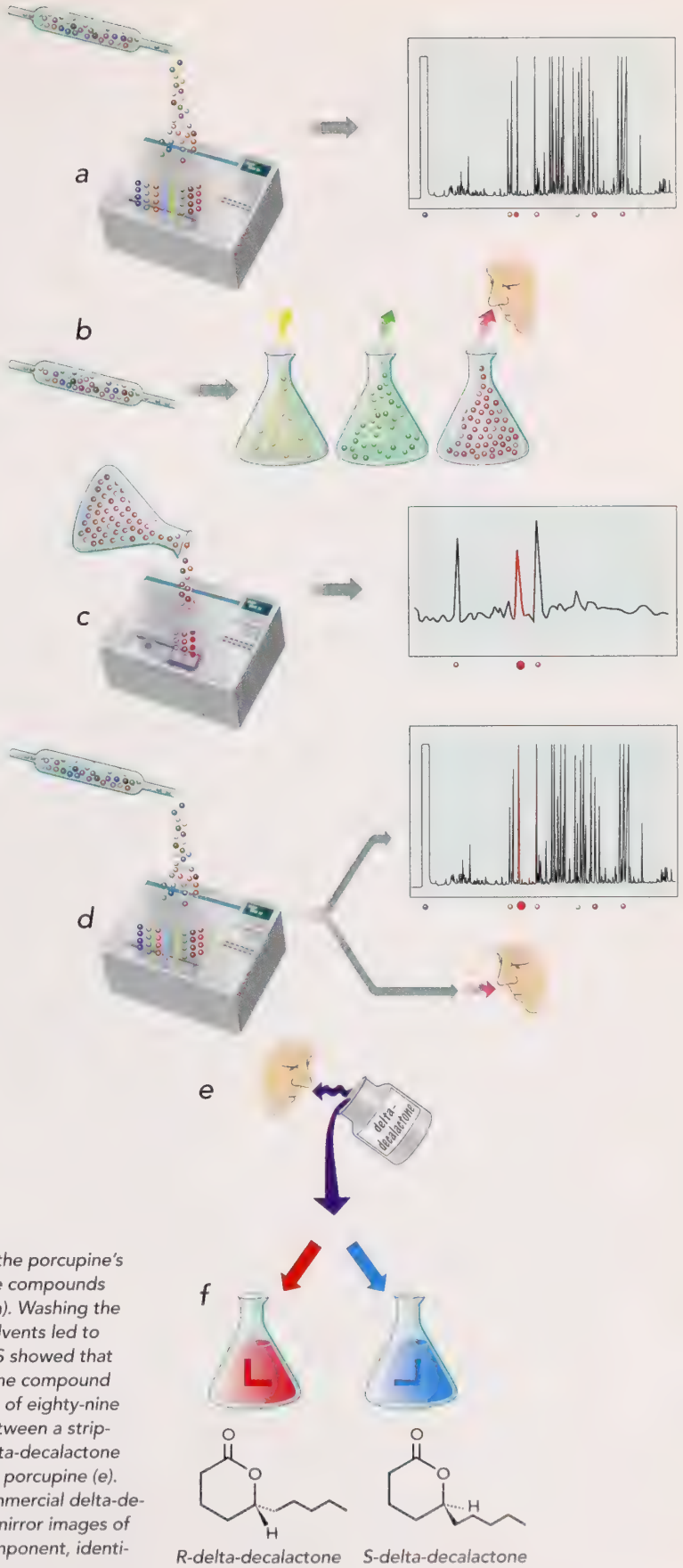
sample of the S-enantiomer from Thomas Haffner, a chemist at the Berlin Technical University. The stuff could all evaporate, so we don't dare sniff it.

Now Guang performs the critical experiment. He runs the commercial mixture of delta-decalactone through the chiral column and, seventy-seven minutes after the process begins, two peaks emerge in the area of the readout where delta-decalactone appears, fifty seconds apart. When Guang spikes the commercial mixture with the S-enantiomer, the first peak enlarges. When he runs only the porcupine sample through the chiral column, a single delta-decalactone peak emerges, coinciding with the second peak of the commercial mixture. The delta-decalactone from the porcupine is therefore R-delta-decalactone. Guang and I shake hands. The project is finished.

What did we learn by assigning a chemical name to an odor we already recognized? We learned something about its uniqueness. The porcupine has a strong interest in sending an unambiguous message. A message that says "porcupine here" is preferable to one that says "perhaps porcupine here, perhaps something else." If a predator has ever had a prior painful encounter with a porcupine, the unique odor would be more likely to trigger the impulse to retreat.

A chemical name is also a specific entry into the large dictionary of natural odors. Smells make up a rich natural language for most mammals, playing a key role in social structure, navigation, and much else. But people for the most part are insensible to the variation and meaning of smells, both for our species and others. At present, the best tool for learning the rudiments of such languages is chemistry.

Chemistry will also help decipher other mysteries of the porcupine, including the fluorescent characteristics of porcupine quills—yet another mechanism of warning off nocturnal predators. That may be a mystery I leave for another scientist. To him or to her, I can offer a very good pair of used vinyl gloves. □



Chemical detective work identified the molecule responsible for the porcupine's distinctive warning odor. The odor was one of eighty-nine volatile compounds detected by a gas chromatograph-mass spectrometer (GC-MS) (a). Washing the same mix of eighty-nine chemicals in three increasingly strong solvents led to three extracts, one of which smelled of porcupine (b). The GC-MS showed that the extract was made up of just three major organics, including the compound delta-decalactone (c). A second run of the raw porcupine mixture of eighty-nine chemicals through the GC-MS split the output simultaneously between a strip-chart recorder and a human nose, confirming that the odor is delta-decalactone (d). But a commercial sample of delta-decalactone didn't smell of porcupine (e). The puzzle was resolved when the investigators realized that commercial delta-decalactone (purple) is made up of two distinct molecules that are mirror images of each other. Once the two were separated (red, blue), the red component, identified as R-delta-decalactone, passed the smell test (f).

Our Anthropoid Roots

Those curious primates from Pondaung, and other leads in the quest for an early ancestor

By Russell L. Ciochon and Gregg F. Gunnell

Who says that scientists can't change their minds, that science progresses only when those who cling to outmoded views die off? In October 1985, *Natural History* published an article about two fossil primates, *Amphipithecus* and *Pondaungia,* which were known from fragmentary specimens discovered in the Pondaung (or Ponnyadaung) Hills of Burma (now Myanmar). The author of that article, following in the tracks of Barnum Brown, the legendary fossil collector from the American Museum of Natural History, had been able to study new specimens unearthed by Burmese paleontologists. On that basis he proposed that the two genera might represent the missing link between prosimians, or lower primates, and anthropoids, or higher primates. That author was one of us—Ciochon—and taking into account new evidence, he now withdraws that conclusion! But those curious primates are still part of the intriguing story of primate origins, and ultimately, of us.

Living prosimians comprise the lemurs and their relatives in Madagascar, as well as several small nocturnal forest creatures: the galagos and pottos of Africa and the lorises of southeastern Asia. Living anthropoids comprise the New World monkeys, Old World monkeys, apes, and humans. Tarsiers, which occur on certain islands in southeastern Asia, are hard to place—they might be prosimians, but they could easily be the closest living relative of the anthropoids.

The tarsier aside, though, the picture of primate evolution seemed fairly straightforward twenty years ago: Prosimians appeared in the fossil record in the northern continents of both the Old and New worlds about 55 million years ago, and anthropoids appeared in Africa around 35 million years ago, presumably having evolved from some prosimian ancestor. Although there was disagreement about which fossil prosimians gave rise to the higher primates, *Amphipithecus* and *Pondaungia* looked like good candidates. At the time Ciochon's article was written, they had both been dated to about 40 million years ago, and they both shared some traits of both prosimians and anthropoids.

In the past two decades, however, that overall picture has dramatically changed. The anthropoid lineage now seems to be as old as the prosimian one, and both may have arisen as long ago as 60 million years. The birthplace of the anthropoids is also up for grabs. Some paleontologists now argue that anthropoids first arose in Asia, not Africa. In that view, their appearance in Africa must have been the result of subsequent dispersal.

The rivalry between Africa and Asia for the affections of primatologists recalls the debate over human origins in the early twentieth century. In his 1871 book, *The Descent of Man,* Darwin surmised that humans evolved in Africa, the native continent of our closest relatives anatomically, the gorillas and chimpanzees. But some specialists, such as Henry Fairfield Osborn, who was president of the American Museum from 1908 until 1933, felt sure that humans first appeared in Asia. Fossils of *Homo erectus* (so-called Peking man and Java man) had already been discovered on that continent. The museum's famed Central Asiatic Expeditions to Mongolia—led by the swashbuckling explorer Roy Chapman Andrews—were financed because their backers expected they would yield the predecessors of *Homo erectus.* Fortunately, the expeditions paid off handsomely in sensational discoveries of dinosaur fossils, for no very early human fossils ever came to light. The fossil evidence for human origins all

Aegyptopithecus and its habitat are depicted in an artist's reconstruction, based on 32-million-year-old fossils. The same region today is much drier and hotter: it lies in Egypt's Fayum desert, about sixty miles southwest of Cairo. About the size of a capuchin monkey, Aegyptopithecus *was an early anthropoid, the primate group whose living representatives are the monkeys, apes, and humans.*

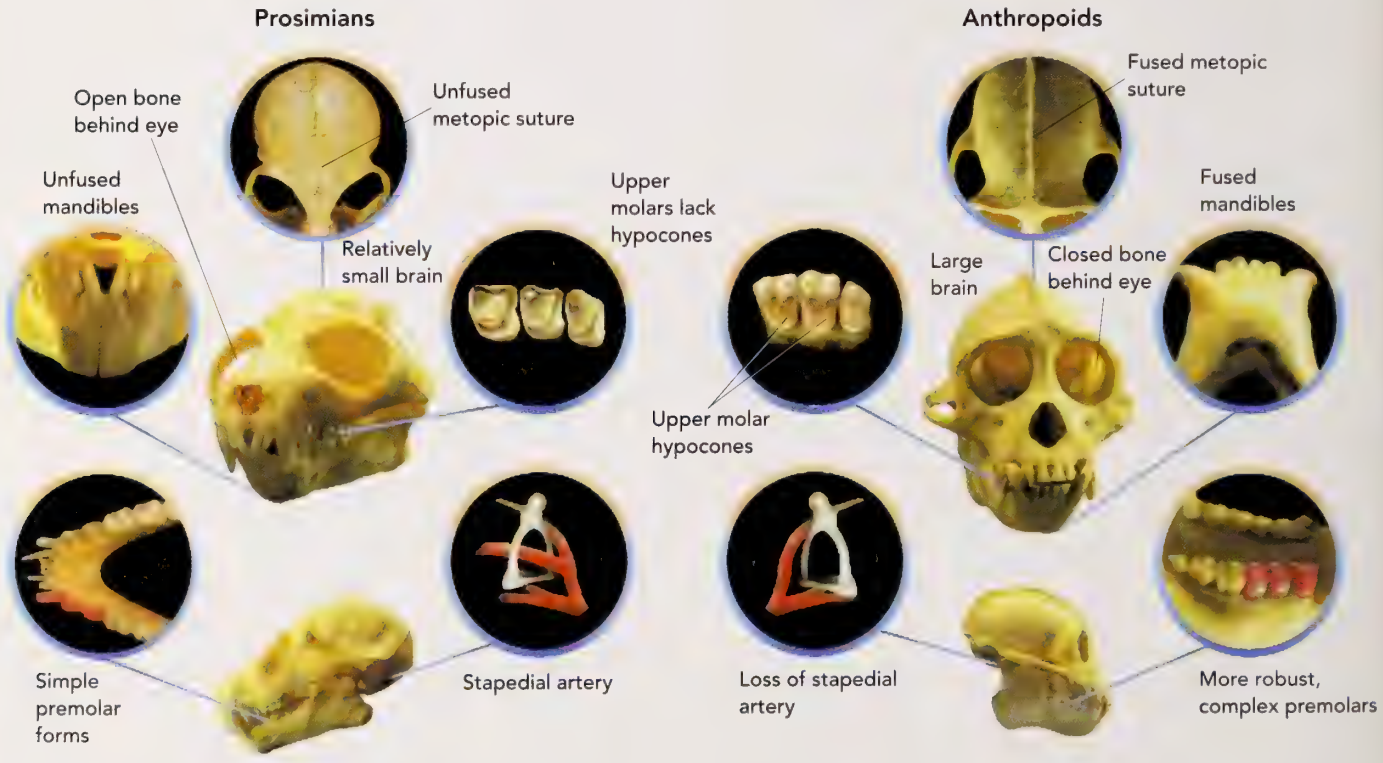
pointed—and still points—to Africa, confirming Darwin's insight.

Although the overall case for African human origins is strong, disputes still rage around important details. For example, did the eastern Asian *H. erectus* or European Neanderthal populations contribute in any way to the gene pool of *Homo sapiens,* or were they dead ends? The questions are not purely of academic interest, as they potentially play into nationalistic and racial preconceptions. One would think the birthplace of our much earlier primate ancestors would not evoke such distractions. Still, the possible honor of that distinction was one reason the Burmese government was so supportive of paleontological prospecting in the Pondaung Hills. And as objective as they try to be, paleontologists are bound to hope that the fossils they discover, wherever they originate, are the centerpiece of some evolutionary story. In that context, the Myanmar fossils and other candidates for anthropoid origins deserve careful evaluation.

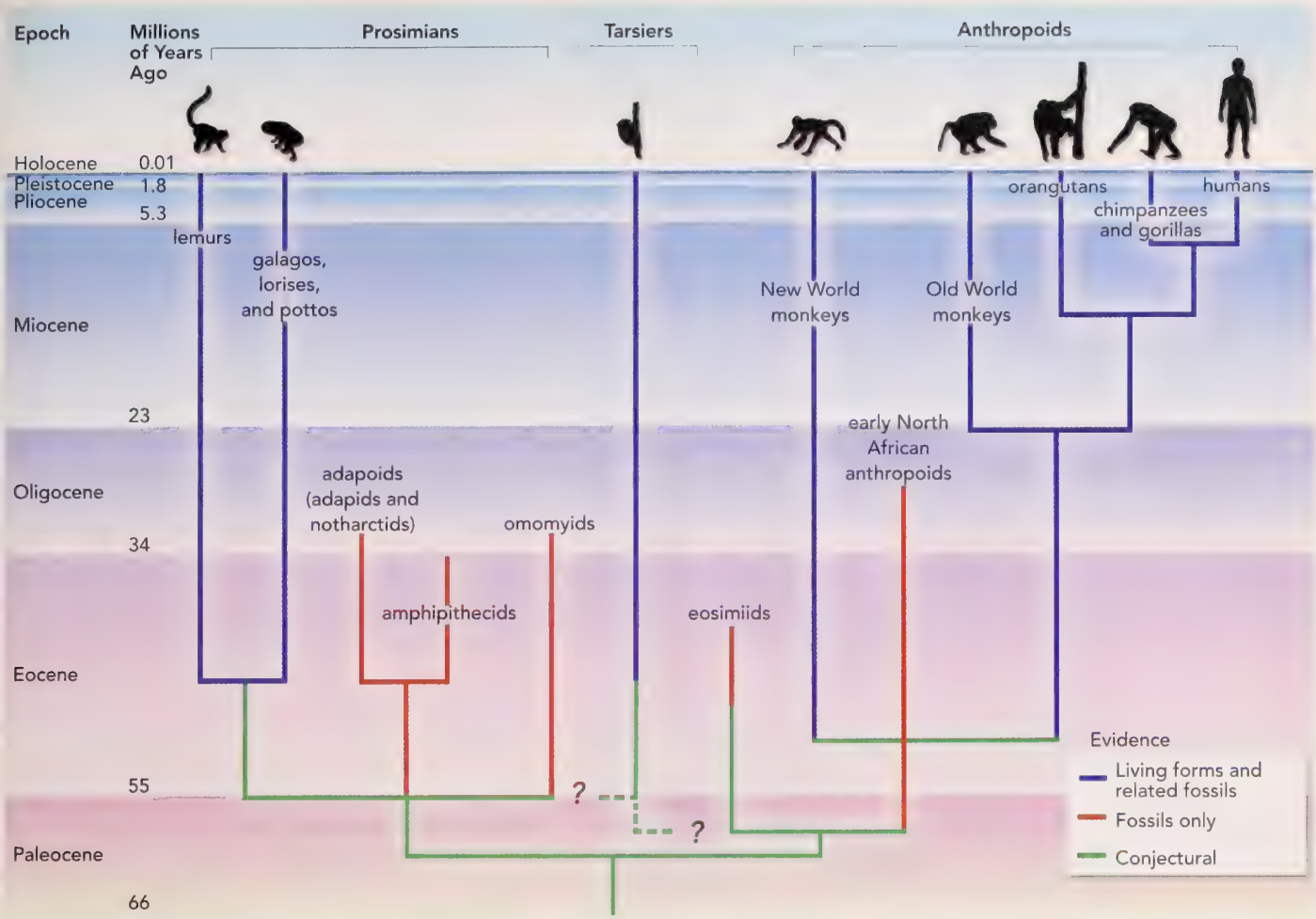
Pondaungia was described scientifically in 1927 on the basis of one specimen, consisting of three jaw fragments, and *Amphipithecus* was described in 1937, on the basis of just one jaw fragment. In spite of the limited nature of the specimens, both bore some resemblance to anthropoid fossils that had been discovered in the Fayum desert of Egypt. Because the Burmese primates appeared to be older than the Egyptian ones, it seemed plausible that anthropoids originated in Asia.

Things started to change in 1978. More and better fossils of both *Pondaungia* and *Amphipithecus* began to emerge in Burma, thanks to the work of American and Burmese teams and, later, French and Japanese teams. At first the new specimens seemed to confirm the anthropoid status of the Burmese primates (hence the title of Ciochon's 1985 article, "Fossil Ancestors of Burma"). But as more complete material began to appear, that view was thrown into doubt.

Today about forty numbered primate specimens have been catalogued from the Pondaung Hills of Myanmar (a specimen sometimes comprises several separate fragments). All told they represent parts of approximately twenty-five individual animals. Among the new discoveries are upper and lower jaws of a new genus, *Myanmarpithecus,* which, along with *Pondaungia* and *Amphipithecus,* has been placed in the family Amphipithecidae (the amphipithecids). *Siamopithecus,* another member of the family, was recently discovered in southern Thailand. In the



Details of primate bones and teeth enable investigators to distinguish anthropoids (above right) and the other main group of primates, the prosimians (above). Other features, including DNA, are useful in determining the family relationships among the living species, but paleontologists generally must rely on the "hard" evidence retained in fossil remains.



Primate family tree, based on living species and fossils, leaves much room for conjecture. The amphipithecids, whose fossils have been discovered in Southeast Asia, no longer appear to be closely related to the earliest anthropoids. The origin of the anthropoids remains obscure.

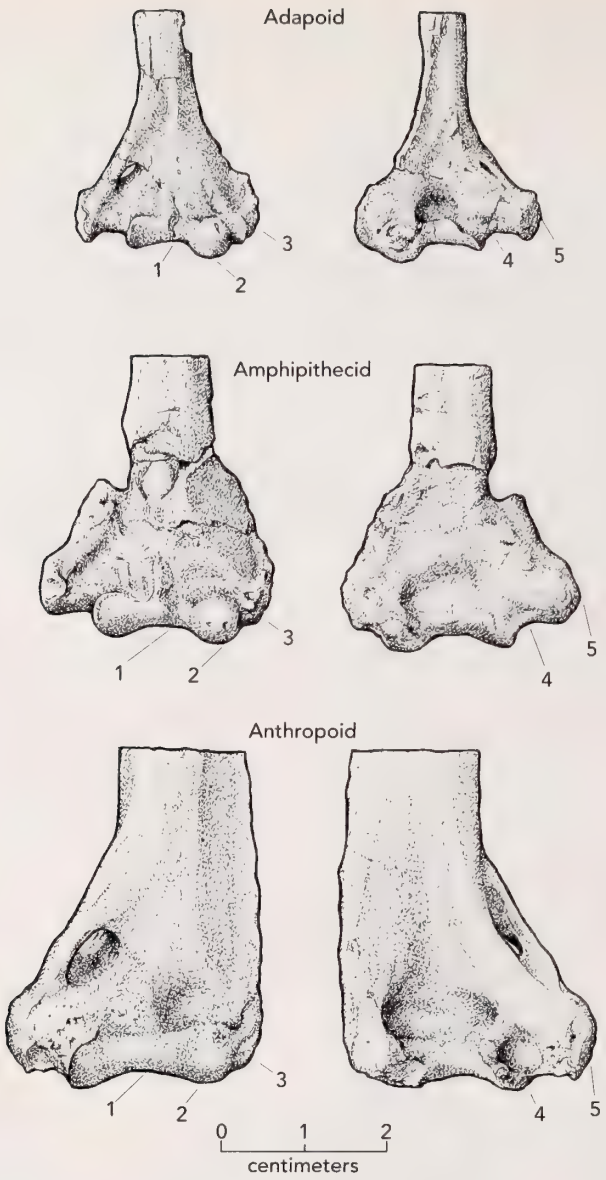
past three years the two of us have examined nearly all these amphipithecid specimens.

Of the forty specimens, two are parts of skeletal bones and another two may be skull fragments; the rest are teeth and jaws. The two skeletal specimens are parts of the arm and the foot; in size, shape, and muscle attachments, both show a close resemblance to the bones of prosimians.

Some paleontologists have questioned whether the two skull fragments are those of primates—or even skull bones at all. But if they are, they indicate an animal that lacked an enclosed eye socket (a bony cup that protects the eye) and had a pair of unfused frontal, or forehead, bones—one on the right and one on the left side of the face, meeting in the so-called metopic suture line. In those respects it contrasts with living anthropoids, which have an enclosed eye socket and a single frontal bone [*see illustration on opposite page*]. Those two anthropoid features are part of a suite of evolutionary changes in the skull that reflect a reorganization and enlargement of the brain and an increased reliance on stereoscopic vision.

What about the amphipithecids' teeth? The molars are flat and bulbous, with thick enamel, not unlike the teeth of those living anthropoids whose diet is made up primarily of fruits and seeds. The teeth tend to be crowded together toward the front of the jaws. The canine teeth are robust but not particularly tall; in living anthropoids they often differ in size according to sex: the male canines are much larger than the female. At the front of the jaws, the incisors look like small, flat shovels, similar to our own incisors. The lower jaws are relatively deep and heavy. On the basis of similar features in living primates, one can infer that the four amphipithecids weighed between three and eighteen pounds and were relatively slow-moving animals that lived in trees.

Although the amphipithecids shared only some features in common with living anthropoids, a more important point is how close they seem when compared



Lower ends of three humeri, or upper arm bones (shown slightly larger than life size, front view at left, back view at right), provide a basis for comparing three fossil primate species: the notharctic Smilodectes mcgrewi *(top), an adapoid that lived about 45 million years ago in North America;* Pondaungia *(middle), one of the amphipithecids discovered in 37-million-year-old deposits in Myanmar (formerly known as Burma); and* Aegyptopithecus zeuxis *(bottom), one of the early north African anthropoids, which dates from about 32 million years ago. Points of comparison, such as the numbered features highlighted in the drawings, suggest that the amphipithecids were closely related to the adapoids.*

with earlier fossil anthropoids. A more enlightening comparison comes from the fossils unearthed at the Fayum site in Egypt, as well as elsewhere in North Africa, where work has progressed in recent years.

By the 1960s two main groups of Fayum anthropoids had been discovered. The more primitive of the two vaguely resembled modern South American monkeys; the more advanced group looked much like modern Old World monkeys and apes. All of them were thought to date from a period older than 25 million years and perhaps as far back as 30 million years. Thus the Fayum anthropoids appeared to be younger, by at least 10 million years, than the amphipithecids, which at the time were thought to date from about 40 million years ago. Both the Burmese and African finds had deep jaws and large, flat teeth, and individuals in both groups were relatively large compared to the prosimians. It was quite plausible to suggest that the amphipithecids could have been ancestors of the Fayum anthropoids.

As work continued in the Fayum, however, along with other work in Morocco and Algeria, several things happened that led to a much more complete picture of North African primate evolution. First, advances in dating technology proved that the primate-bearing rocks in the Fayum spanned an earlier time period than previously thought, between 37 million and 31 million years ago. Second, better specimens of previously known forms were discovered. And third, new anthropoids from older rocks in the Fayum and in Algeria and Morocco were discovered.

The earliest known anthropoids from Algeria and the earliest parts of the Fayum turned out to be as small as, or even smaller than, their prosimian relatives. They also proved to date from between 50 million and 37 million years ago, making them as old as or older than the amphipithecids. Given that the age of the Myanmar amphipithecids is now firmly fixed at about 37 million years ago, it is difficult to imagine how they could have been the ancestors of older African anthropoids. If that were not evidence enough, the teeth of the amphipithecids have more in common with those of the later and larger Fayum primates than they do with the teeth of the earlier ones. It has also become clear that all the African skulls, in contrast with the possible skull fragments of the amphipithecids, shared the specialized features characteristic of living anthropoids.

So how do the curious amphipithecid primates from the Pondaung Hills fit into the primate group as a whole? Are they the lone representatives of an isolated and long-extinct primate line? Or do they share features with some other, non-anthropoid primate group? We favor the second hypothesis. Nearly all the features of amphipithecids are also characteristic of a group of lemurlike prosimians that flourished across all of the northern continents between 55 million and 34 million years ago.

Those latter prosimians, comprising the adapids and the notharctids, form a group known as adapoids,

or adapiforms. They also lack the skull specializations of anthropoids. Their teeth also come in a wide variety of forms, some of which, in most details, resemble the teeth of amphipithecids. But the greatest similarities lie in the skeleton. In fact, if you carried an upper arm bone of *Pondaungia* to Wyoming and laid it on a hill in the badlands, the next paleontologist to come along would readily identify it as an adapoid. *Pondaungia* resembles the known Wyoming adapoids so closely that no one would be surprised to find it there [*see illustration on opposite page*].

Most of the adapoids became extinct before 40 million years ago, but some from coastal California and coastal Texas survived longer. The latter, like the amphipithecids, some of which lived as late as 34 million years ago, probably represented relict populations that survived in isolated tropical belts near coastal areas. There the cool and dry climate typical of the continental interiors had yet to take hold.

The amphipithecids were the first Eocene primates to be recognized from Asia. For many years, in fact, their fossil remains constituted the only evidence in support of a possible Asian ancestry for anthropoids. Some scholars still advocate that view. In recent years, however, a new group of primates known as the eosimiids has replaced the amphipithecids as the leading Asian candidate for the title "earliest anthropoid." The eosimiids were small animals that have some dental features in common with early Fayum anthropoids. Paleontologists who champion them as anthropoid ancestors suggest that the group, like the amphipithecids, arose in Asia and subsequently dispersed into Africa. The difference is that the eosimiids would have had to begin migrating out of Asia more than 60 million years ago.

Such an early dispersal, however, is hard to square with geographic reality. A wide body of water known as the Tethys Sea separated Africa from Asia 60 million years ago. An arm of that sea, known as the Obik Sea, divided Asia from Europe. The prevailing ocean currents would have prevented most animals from rafting from Asia to Africa or from Asia to Europe and then on to Africa. There is evidence of limited migration between Africa and Europe as early as 60 million years ago, but no sign of an African-Asian interchange. Not until much later, about 33 million years ago, is there evidence of even limited migration between Africa and Asia.

There are more problems for the hypothesis that eosimiids were the first anthropoids. Like amphipithecids, eosimiids are known only from highly fragmentary specimens, and many features of their teeth look decidedly nonanthropoid. Moreover, like the fossils of the amphipithecids, the known fossils of eosimiids are too young. The earliest known eosimiid fossils date from 47 million years ago, whereas African anthropoid fossils from Algeria go back at least 50 million years. (A 60-million-year-old Moroccan fossil may also be an anthropoid, but that conclusion is in dispute.) At best, the eosimiids may represent an early, Asian anthropoid lineage that turned out to be an evolutionary dead end.

In short, the search for the earliest anthropoid ancestor must go on. Whether that elusive creature lived in Asia or Africa, or even Europe or North America, is still a puzzle that future paleontologists will have to solve. □

Notharctus venticolus, an adapoid shown here in an artist's reconstruction, inhabited what is now Wyoming about 50 million years ago. Although the adapoids left no living descendants, they remain part of the broad picture of primate origins.

Mesas near Independence Creek, despite being separated by canyons, rise to a uniform height, revealing the underlying unity of the Edwards Plateau.

Mesa Country

Independence Creek creates a wetland oasis in an arid Texas landscape.

By Robert H. Mohlenbrock

The largest geographic region in Texas is the Hill Country, or, more formally, the Edwards Plateau, an elevated plane the size of Pennsylvania laced with canyons and flat valleys. The dramatic Balcones Escarpment bounds the plateau to the east and south. To the north, the terrain is carved by relatively shallow canyons; to the west, the plateau blends into the Chihuahuan Desert. The climate in the western zone is decidedly arid, but even in the east it is at best semiarid. Overall, the terrain is rocky; surface soil usually comprises sand or clay mixed with calcium carbonate or other carbonates, a combination known as caliche. Some 98 percent of the plateau serves as rangeland for cattle, goats, and sheep.

Deep canyons cut into the western portion, also known as the Stockton Plateau. A few permanent streams, fed by natural springs, nourish wetland flora within just a few yards of such desert plants as barrel cactus, creosote bush, and ocotillo [*see "Two Faces of Texas," by Robert H. Mohlenbrock, October 2004*]. One such stream is Independence Creek, a ninety-mile-long tributary to the Pecos River. Along the creek, the Nature Conservancy has acquired three ranches totaling about thirty-seven square miles, which is now called the Independence Creek Preserve. With the permission of its stewards you can visit the preserve [*see contact information on opposite page*].

Independence Creek

One-fourth of the flow in Independence Creek comes from Caroline Spring, situated at the preserve headquarters. The spring feeds a seventy-five-foot-wide pool that connects to the creek via a short, narrow tributary. Limestone cliffs act as a serene backdrop to picnic facilities overlooking the pool. Coastal water hyssop, roundleaf seedbox, spiny naiad, and two species of pondweed are visible in the crystal-clear water, and fronds of southern maidenhair fern hang gracefully from the limestone rocks. Downstream from the pool, Independence Creek flows for fifteen miles before emptying into the Pecos.

In one woods along the west side of the creek is a small tree with beautiful orchidlike flowers, known as Texas plume or Anachaco orchid *(Bauhinia lunarioides)*. The genus *Bauhinia* is almost entirely tropical: it includes more than 400 species,

but Texas plume is the only one native to the United States.

Most species of *Bauhinia* have symmetrical bilobed leaves. The two lobes may have inspired the eighteenth-century Swedish taxonomist Carl von Linnaeus, who in 1753 named the genus in honor of a pair of Swiss botanists, the Bauhin brothers. Although the Bauhins lived more than a century before Linnaeus, one of them, Gaspard, was the first to list plants by giving them two names according to a classification system. Thus Gaspard Bauhin was the true inventor of the binomial system of nomenclature, which is generally credited to Linnaeus.

Zone-tailed hawk

Wetland plants and trees abound along and in Independence Creek. Away from the stream, however, drier plant communities immediately begin to appear. The slopes between the mesas and the canyon floors are dominated by Ashe juniper and redberry juniper, along with ocotillo, a cactuslike plant with long, slender stems. The flat mesa tops are also dotted with Ashe juniper and ocotillo, mixed with beargrass and wheeler sotol. Other species appear along the large boulders, cliffs, and ledges at the edges of most of the mesa tops.

One moist habitat of interest is a small woods near the confluence of Independence Creek and the Pecos River. It is the nation's westernmost stand of plateau live oak, and the principal nesting site of the black-capped vireo, a bird on the federal list of endangered species.

Other species the avid north-of-the-border birder can add to his or her life list are the tropical parula and zone-tailed hawk. Among the rare reptiles are the Big Bend blackhead snake and the Texas horned lizard. Native fish in the waters include the headwater catfish, proserpine shiner, and Rio Grande darter, the latter two listed by the Texas Parks and Wildlife Department as threatened species.

VISITOR INFORMATION
Independence Creek Preserve
P.O. Box 150
Dryden, TX 78551
432-345-6773
http://nature.org/texas

ROBERT H. MOHLENBROCK is a distinguished professor emeritus of plant biology at Southern Illinois University Carbondale.

Habitats

Streamside Shrubs and small trees in the creek or along its banks include black willow, buttonbush, and desert willow, a Chihuahuan Desert plant. French tamarisk, an invasive species from Europe, has made some inroads.

Bushy bluestem, a grass with thick, reddish brown spikelets, is common. It often grows with tule, a tall, narrow-leaved cattail. Another common wetland grass is rabbitfoot polypogon, named for its soft, hairy, flowering spikelets. Stands of common reed, an invasive species from the eastern U.S. seaboard, appear here and there.

Wetland sedges include several species of spikerush; one has stems that grow so long that they bend down to the streambed and form roots at their tips. Among the other sedges are two species of flatsedge, which grow three feet high; olney bulrush, a leafless plant with sharply angled three-sided stems; and western umbrellagrass, with small prickly-looking flowering spikelets.

Among the wildflowers are such low-growing species as coast brookweed, spadeleaf, turkey tangle, water pennywort, and the rare low loosestrife. Larger herbs include American germander, giant goldenrod, purple marsh-fleabane, and woolly rosemallow.

Steep bank This habitat above the streambed is usually dominated by small-leaved, gnarly shrubs and trees, such as honey mesquite, javelina bush, knifeleaf squawbush, littleleaf sumac, netleaf hackberry, Texas persimmon, and wait-a-minute bush.

Canyon head Small trees grow at the heads of canyons above the creek. The dominant species are Ashe juniper and two kinds of shin oak. Beneath them grow the shorter Texas mountain laurel; Mexican buckeye, so-called because its fruits resemble those of true buckeyes; and desert myrtlecroton. The Texas plume lives in this habitat.

Mesa slope Ashe juniper, ocotillo, and redberry juniper grow on most of the slopes between the tops of the mesas and the canyon floors. Common associates are agarito, Texas silverleaf, and the yuccalike wheeler sotol.

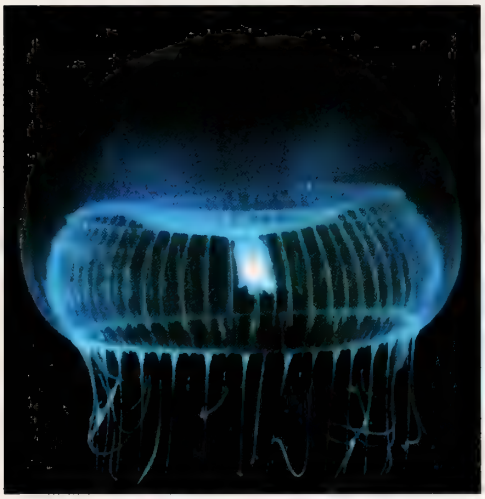
Mesa top Ashe juniper and ocotillo mix with beargrass and wheeler sotol. Buffalograss and tobosa usually provide ground cover.

By Laurence A. Marschall

Aglow in the Dark: The Revolutionary Science of Biofluorescence
by Vincent Pieribone and David F. Gruber
Harvard University Press, 2005; $24.95

Wombats don't normally glow in the dark; neither do albatrosses. Except for a small assortment of insects such as fireflies and glowworms, creatures on land or in the air seldom need to make their own light. Even when it's cloudy, the Sun, Moon, and stars provide ample illumination for finding food and signaling companions.

In the ocean, though—particularly at depths beyond the reach of sunlight—bioluminescence is the rule.



Colorless jellyfish (Aequorea victoria) *was the source of the first bioluminescent protein to be chemically characterized. The jellyfish in this photograph is lit to show its morphology; it emits its own light only in discrete dots around the margin of the bell.*

The female humpback anglerfish *(Melanocetus johnsoni)* dangles a glimmering lure from a stalk on its snout to beckon its prey. The luminescent edible clam *(Pholas dactylus)* signals distress by squirting a glowing blue liquid from its siphon. The male sea firefly *(Cypridina hilgendorfi)* rises toward the surface when ready to mate, spitting out punctuated streams of liquid light as he goes. His female counterpart pursues those luminescent strings to their source, homing in on her sweetheart like a pilot following runway lights safely into an airport.

What all these creatures have in common are proteins closely associated with light-emitting molecules called luciferins. In the presence of triggering chemicals, luciferins convert chemical energy directly into light without heating, a cold luminosity that is both strange and mysterious. Light-producing reactions were first probed in 1887, but only in the late decades of the twentieth century were they understood as more than incidental curiosities.

Even in luminescent organisms, only traces of bioluminescent proteins are present. That scarcity long kept chemists in the dark about their molecular structure. Then, in 1961, the Japanese biochemist Osamu Shimomura collected and dissected more than 9,000 jellyfish of the species *Aequorea victoria*. It took a year for Shimomura to purify a macroscopic quantity of a protein that he called *aequorin*, the bioluminescent substance from the mashed jellyfish. But with the stuff in hand, he showed that the jellyfish turned its light on and off by regulating the amount of calcium in its cells.

Shimomura's discovery marked the beginning of a boom in research about light emitted by biochemicals. Aequorin's ability to signal calcium levels made it an ideal substance for probing the chemistry of living organisms: inject a little aequorin into the cells of another creature, from a lowly barnacle to a tool-making baboon, and given the appropriate level of calcium, the aequorin would turn on like a pilot light. Experimenters could know at a glance when calcium was flowing into a muscle or a nerve.

Vincent Pieribone, a neurophysiologist at Yale University, and David F. Gruber, a doctoral candidate in oceanography at Rutgers University in New Brunswick, New Jersey, are among the many scientific beneficiaries of that pioneering work. New molecular techniques make it possible to manufacture large batches of light-emitting proteins in fermentation vats. You no longer have to decimate marine populations to discover new light-emitting molecules. Even more important, thanks to the genetic revolution, DNA sequences that code for light-emitting molecules can be attached to specific genes of virtually any creature, giving rise to cells that glow only when those genes are expressed.

Thus, by tagging genes with molecules that literally flash their presence at the microscopic level, biologists can pinpoint the sites of tumors, observe the development of degenerative diseases such as Alzheimer's in living creatures, trace nerve action, and the like, all in cell-level detail.

The Rock from Mars: A Detective Story on Two Planets
by Kathy Sawyer
Random House, 2006; $25.95

ALH84001 is its name, a fist-size lump of rock discovered near the Allan Hills in Antarctica back in 1984. At NASA's Johnson Space Center in Houston, where the rock was sent for study, meteoritic experts determined that it had been ejected from the surface of Mars during the planet's collision with a small comet or asteroid. After wandering the inner solar system for about 16 million years, ALH84001 collided with the Earth, landing on the Antarctic ice sheet some 13,000 years ago. Several dozen meteorites of similar composition have been discovered over the years, and investigators agree that they all originated on Mars.

When it comes to ALH84001, however, Martian citizenship is virtually the only point of expert agreement. In the early 1990s David S. McKay, a geochemist at NASA, and a group of colleagues studying the rock became convinced that it held evidence of biolog-

ical activity. Embedded throughout its interior are small globules of carbonate materials, along with complex hydrocarbons called polycyclic aromatic hydrocarbons (PAHs). In terrestrial rocks, carbonates and PAHs are often—though not always—produced by microorganisms. Even more striking was another internal feature of the rock: wormlike tubules, one-hundredth the width of a human hair, which resembled Precambrian microfossils that had previously been reported in terrestrial rocks more than 3 billion years old.

In April 1996 the NASA geologists and their collaborators submitted a paper to the prestigious journal *Science,* titled "Search for Life on Mars: A Study of Martian Meteorites"; three months later the paper was accepted for publication.

Few papers in *Science* have drawn such rapt attention. On August 7, 1996, a week before its publication, with leaks about NASA and life on other planets about to appear in the press, President Clinton appeared on the South Lawn of the White House to announce the remarkable discovery: "Today, rock eight four oh oh one speaks to us across all those billions of years and millions of miles. If this discovery is confirmed, it will surely be one of the most stunning insights into our universe that science has ever uncovered."

Kathy Sawyer, a veteran science writer for *The Washington Post,* describes what happened at the press conference immediately following the president's announcement. ALH84001 went into the conference as the celebrity of the day, but it emerged with a reputation as controversial as Michael Jackson's. Daniel Goldin, the dynamic NASA administrator, spoke enthusiastically of the progress of science, followed by a sober and detailed presentation of the evidence by McKay and his collaborators. But when the microphone passed to an independent commentator, "designated skeptic" J. William Schopf, the tone of optimism changed abruptly. Schopf, a UCLA paleobiologist, put his assessment bluntly. "I think," he told the conference, "a lot more additional work needs to be done before we can have firm confidence that this report is of life on Mars."

In this expert chronicle of the sometimes acrimonious controversy that followed, Sawyer provides a razor-sharp portrait of good science at work. Hers is a story of conscientious investigators using state-of-the-art techniques on a problem with no simple resolution, unlike the comedy of errors over cold fusion in the 1980s. Informed observers have still not reached agreement on the "wormlike" features in ALH84001. Some have questioned the supposed biological origin of similar microfossils in ancient terrestrial rocks. And almost ten years after that August news conference, the "additional work" that Schopf recommended continues: on the Antarctic ice sheet, in high-tech laboratories on Earth, and even on Mars itself.

Men of Salt: Crossing the Sahara on the Caravan of White Gold
by Michael Benanav
The Lyons Press, 2006; $23.95

What am I doing? Michael Benanav asks himself rhetorically, about halfway through this travelogue. "A Jewish guy raised in suburban Connecticut chasing a camel train across the Sahara . . . just to pick up some salt?" The answer is, as the reader soon learns, having a wonderful time. For writers such as Benanav, who like their journeys primal, places where you can have a genuine adventure nowadays—out of range of cell phones, soft-drink machines, and *caffè macchiatos*—are almost impossible to find. But the road from Timbuktu to Taoudenni is certainly one of them.

Camel caravans regularly travel the route, making the round-trip in about a month. Taoudenni, Mali, situated deep in the Sahara Desert, is as barren as the surface of Mars. Even after traveling for days through the Tanezrouft, a part of the desert known to the local Tuareg tribesmen as "The Land of Thirst," Benanav is floored by the absolute desolation of its only inhabited location. "[Taoudenni] is situated on utterly lifeless desert flats; not a single leaf, or even thorn, grows from the parched, dusty dirt, which was so sharp it bit into the soles of my bare feet."

So what draws people to Taoudenni? One word: salt. For centuries enterprising nomads have led trains of camels there to pick up eighty-pound plates of rock salt chiseled from an ancient seabed by a hardy population of miners. At Taoudenni the heat is hellish, the well water brackish, and the housing little more than a cluster of dirt huts made of rubble from the mines. But Saharan salt brings a good price back in more civilized parts, and there aren't many other ways to earn cash in this impoverished

Young Tuareg men lead a train of camels, laden with slabs of salt, across the Sahara to markets in Timbuktu, Mali.

land. Benanav, a true twenty-first-century adventurer, first read about the place on the Internet, then developed an itch to see it for himself.

Now, a quick glance at the Web shows that you can travel to Taoudenni in relative comfort: there are outfitters willing to whisk tourists out and back in vehicles with four-wheel drive. Benanav wanted none of that. He wanted to ride with the camels, burn camel dung to boil his tea, and dine on the same sandy rice and dried goat meat that real caravan drivers eat.

Fortunately, he located a former camel driver named Walid who was willing to take a crazy American to a place most Tuaregs viewed with fear and disgust. Even more fortunately, Benanav knew enough Arabic to converse a bit with his guide, and he and Walid hit it off right from the start. By the end of chapter one, the two men, astride two camels, have set out from Timbuktu to join the salt merchants on their journey. What follows is indeed a rousing adventure, with enough rancid meat, dust storms, thirsty days, and star-spangled nights to keep the pages turning.

LAURENCE A. MARSCHALL, author of The Supernova Story, *is the W.K.T. Sahm professor of physics at Gettysburg College in Pennsylvania. He is the 2005 winner of the Education prize of the American Astronomical Society.*

nature.net

First Animals

By Robert Anderson

The geologic timescale was one of the great achievements of nineteenth-century science. Yet the oldest named division of geologic time was the Cambrian, beginning 540 million years ago. All time before the Cambrian was a great unknown, simply designated Precambrian, even though life on Earth began more than 3.5 billion years ago. The earliest multicelled animals, for instance—enigmatic, mostly soft-bodied creatures that lived in the latest phase of the Precambrian—only rarely left fossils.

But recently the International Commission on Stratigraphy (ICS) came up with an official name for the 80 or so million years immediately preceding the Cambrian: the Ediacaran period. Interest in Ediacaran times has grown, because the fossils show that the period marks an unprecedented flowering in the diversity of life-forms following the end of a global freeze-over.

At the ICS Web site (stratigraphy.org/down.htm), click on one of the international charts to get the latest official update. Nail icons on the multicolor timechart indicate a specific layer of rock somewhere in the world that serves as the base of its period. The baseline for the Ediacaran, for instance, is a postglacial carbonate layer in the Enorama Creek section of the Flinders Ranges, some 250 miles due north of Adelaide, Australia. The name for the new period comes from the Ediacara Hills, a 570-million-year-old site in the Flinders Ranges where some of the first animals big enough to be seen with the unaided eye are preserved in good detail. The Palaeos site (palaeos.com/Ecology/Biota/Ediacara.html) has more information on those animals, along with a list of links.

In "The Measure of Deep Time," at the Web site of NASA's Astrobiology Institute, writer David Morrison gives a summary of the new slice of time, with an illustration of the key events that define it (nai.arc.nasa.gov/news_stories/news_detail.cfm?ID=291). At www.paleoportal.org/time_space/period.php?period_id=17 you can find out whether there are Precambrian rocks in your area. Click on the arrow beside "Any state." At talkorigins.org/origins/faqs-youngearth.html you'll find several pages related to the construction of the geologic timescale.

Go to www.palaeos.com/Proterozoic/Neoproterozoic/Neoproterozoic.html to get a quick rundown on what it must have been like to live on our planet during the Ediacaran. At the Miller Museum of Geology in Kingston, Ontario, an online exhibit of "The Dawn of Animal Life" (geol.queensu.ca/museum/exhibits/dawnex.html) has many images of the latest Precambrian fossil discoveries. On display in the physical museum are the oldest animal fossils in the world, spongelike rings dating back 600 million years. At the Smithsonian's early life exhibit you'll find a wonderful diorama (www.mnh.si.edu/museum/VirtualTour/Tour/First/Early/index.html) that brings the Ediacaran back to life.

The University of California Museum of Paleontology in Berkeley has another online exhibit of the earliest animals, along with a map (click on "Localities") of where some of the fossils were discovered (www.ucmp.berkeley.edu/vendian/vendian.html). To confuse matters, this site, like many others, has not yet adopted the name Ediacaran. Instead the sites use the alternate, Russian name—Vendian—a name derived from Siberian strata of the same age.

The most remarkable Ediacaran-age discovery comes from the Doushantuo Formation in southern China. Here, ancient tissue was replaced by calcium phosphate, preserving the cellular structure of small sponges and jellyfish in exquisite detail. Even microscopic eggs and embryos are visible. But most exciting of all is the 2004 discovery of the oldest known "bilateran," an animal with bilateral symmetry, whose descendants include everything from worms to us. Investigators have so far identified ten bilaterans—each about the size of the period at the end of this sentence. Go to pharyngula.org/index/weblog/comments/pre_cambrian_coelomate to read more about those remarkable fossils.

ROBERT ANDERSON is a freelance science writer living in Los Angeles.

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But perhaps the most far-reaching and successful solution to the most fundamental and persistent problem encountered by the space sciences—detecting the bucket of light—has been the charge-coupled device, or CCD.

A CCD is a light sensor made of a tiny silicon chip, subdivided into a grid of hundreds of thousands or even millions of extremely sensitive "picture elements"—a term shortened in 1969 to "pixel." Each pixel is like a little well, holding a cache of electrons. Nearly every time a photon hits a pixel, an electron gets kicked up out of the well, where it waits to be counted. At the end of each exposure, hardware and software associated with the CCD do just that. Counting and remembering all the electrons from each well yields a grid of numbers that captures the brightness of the object, region by region.

The efficiency of today's best CCDs exceeds 90 percent: for every hundred photons that land on the CCD, at least ninety get recorded. By comparison, the emulsions on the best photographic plates register no more than one in a hundred photons. In other words, a one-hour exposure for a CCD is the equivalent, in detection sensitivity, to a hundred hours of exposure for a photographic plate. And unless you're at or near Earth's poles, nights don't last that long.

The CCD has transformed astrophysics. If you can detect 90 percent of the available light, why worry about the rest? And if you attach a relatively inexpensive CCD to a backyard telescope, you can wield as much detection power as astrophysicists did thirty years ago, equipped with some of the best telescopes in the world.

Another virtue of the CCD is that the picture is born digital, making it a cinch to work with the data. Say your picture looks almost uniformly gray; maybe the number of electrons per pixel covers the narrow range from 990 to 1,010. But maybe some important science can be gleaned from those variations. So, for the display screen, you assign black to 990 and white to 1,010, and you lay the entire gray scale between those two extremes. Suddenly 995 looks very different from 1,000. What was previously a nearly uniform image now has bright and dark spots popping out everywhere. And if your data happen to measure temperature, and you assign colors to the gray scale—say, blue for coldest and red for warmest—you might even end up with an image that resembles the unprecedentedly detailed portrait of the cosmic microwave background made in 2003.

During the twentieth century the astrophysicist's toolbox grew exponentially. Telescopes and detectors now tune to every band of light across the electromagnetic spectrum, from radio waves through gamma rays. Multiple telescopes, arrayed across dozens and, in some cases, thousands of miles, are electronically linked to make an interferometer that mimics the resolution of a single telescope as wide as the array itself.

Other telescopes orbit high above Earth's turbulent atmosphere. The exorbitant cost of putting them there has prompted the growth of ground-based adaptive optics: systems of sensors that continuously monitor atmospheric turbulence and feed their data to telescopes that can actively compensate for changing conditions. The crispness of the resulting images rivals that of images from spaceborne telescopes.

Sky watchers, no longer constrained by the narrow vistas of a world without spyglasses, now delight in one where countless outsize telescopes, on Earth and in the heavens, leave no cosmic vista unobserved.

Astrophysicist NEIL DEGRASSE TYSON *is the director of the Hayden Planetarium at the American Museum of Natural History. His* Natural History *essay "In the Beginning" (September 2003) won the 2005 Science Writing Award from the American Institute of Physics. An anthology of his* Natural History *essays will be published in 2006 by W.W. Norton.*

A Will to Give

Dr. Christopher Raxworthy, Curator of Herpetology and Barbara Mumé, Museum archivist, review some of the hundreds of artifacts Roger Conant bequeathed to the Museum. (Photos by Craig Chesek/AMNH)

Roger Conant's extensive field research included scientific studies published by the American Museum of Natural History on the water snakes of Mexico. A bond of affection and respect was forged between Roger and his colleagues at the Museum over the years. He recently left a generous bequest to the Museum to further its work. It included cash, specimens he began to send the Museum in the 60's and more recent acquisitions of his field notes, correspondence, hand-painted illustrations and his original typewriter.

Isabelle Hunt Conant and Roger Conant photographing frogs for their catalogues (From the Isabelle Hunt Conant Memorial Photographic Collection)

If, like Roger Conant, you want to contribute to the greater good with a special bequest to your beloved AMNH, please contact us for the appropriate legal language to use in your will. We have a special brochure to give you that will explain this. Just call us at (212) 769-5119, or e-mail: plannedgiving@amnh.org. You may be assured of confidentiality.

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Slammin' the Milky Way

The majestic calm in the stellar disk of our galaxy may conceal a history of intergalactic collisions.

By Charles Liu

NEW GALAXY SLAMS INTO THE MILKY WAY, blared the headlines in January. At the winter meeting of the American Astronomical Society, a research team led by Mario Juric at Princeton University announced that they'd found a dwarf galaxy, a gathering of millions of stars, crashing into our home galaxy.

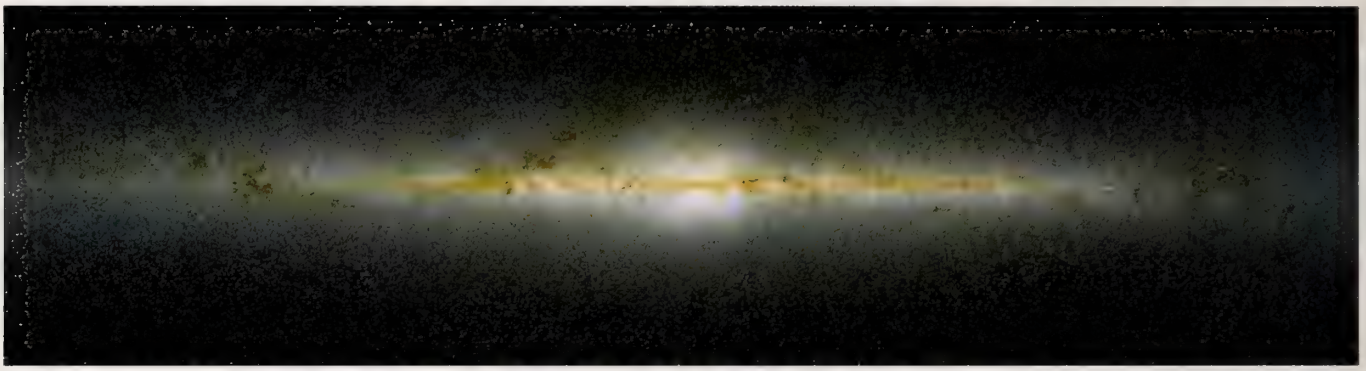
Exciting news, yes—but maybe not as dramatic as it seemed in the newspapers. We astronomers are pretty sure that a lot of dwarf galaxies have fallen into the Milky Way in the past 10 billion years. And because the stars are all so far apart that they don't actually hit each other, and since the dwarfs are eventually fully incorporated into the Milky Way, they're really more like mergers than crashes. Even so, they can have a noticeable impact on the structure of our galaxy, even billions of years after the fact.

How about an example? First, a few bits of background: The Milky Way is shaped like a pancake with a plum stuck through the middle. The plum is called the galactic bulge; the pancake, known as the galactic disk, is a mighty flat flapjack—about 100,000 light-years across but only a hundredth that thick. Together, the galactic disk and bulge are embedded in a sparse stellar sphere, a "galactic halo" some 150,000 light-years across.

About twenty years ago, yet another component of our galaxy's stellar structure was identified. A substantial number of stars was discovered near, but not in, the superthin galactic disk—stretching more than 2,000 light-years above and below the main plane of stars. The extra stars also orbit the galactic center, but unlike stars belonging to the disk, they move both faster and more randomly. Astronomers concluded that the galaxy had both a main, thin disk as well as a "thick" disk—a sparse, puffed-up structure that envelops its companion.

How did the thick disk form? The leading hypothesis says a small dwarf galaxy collided with the Milky Way.

As I noted earlier, you can imagine such galaxy mergers as cannibalistic collisions. The gravitational effects of a merging dwarf galaxy, it turns out, can seriously disrupt the Milky Way's disk. If a small dwarf galaxy had fallen into the Milky Way long ago, it might have "splashed" up and down through the thin galactic disk several times as it settled gravitationally into our galaxy. Those disruptions might well have given some of the stars extra random motion and created a thicker, puffier disk. Or, even after billions of years, some of the dwarf's stars may still not have settled into the more massive and stable Milky Way disk. In that case, the thick disk could be made up of those "unsettled" stars.



The bulge and disk of our home galaxy, the Milky Way, are shown in this composite image, assembled from infrared images collected with the Two Micron All Sky Survey.

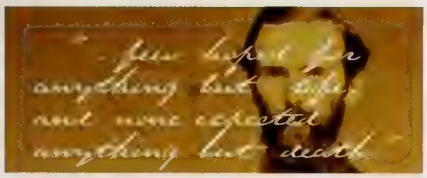
Mary-Margaret Brewer at William Jewell College in Liberty, Missouri, and Bruce W. Carney at the University of North Carolina, Chapel Hill, are studying long-lived, sunlike stars in both the thin and the thick disks of the Milky Way. Their goal is to determine whether stars in the two disks formed in common or in disparate settings.

Stars, like people, are what they eat—or rather ate. Each star is born with the same elements, in the same ratios, that were present in the vast clouds of gas and dust out of which the star formed. So in principle, to determine whether two stars were born in

(Continued on page 74)

The date makes it rare. A war, a hurricane and a shipwreck make it the stuff of legend.

(Shown larger than actual size)



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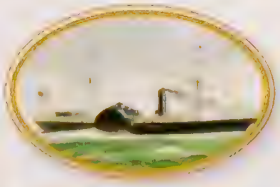
Survivor of SS Republic Shipwreck

The legend began on a cold Wednesday morning in October of 1865 on New York's East River. There at pier nine, the SS *Republic* sat low in the water - laden with barrels of silver and gold coins bound for New Orleans to help rebuild the Civil War torn South.

The first few days of the voyage were uneventful. Then on Sunday, Captain Edward Young observed storm clouds gathering ominously on the horizon. He kept a vigil as the sea grew fierce. By midday next, the 210-foot paddle wheeled steamer was pushing through huge Atlantic swells - frantically trying to outrun a hurricane and save passengers and crew from almost certain death.



The double paddle wheel SS *Republic* was a state-of-the-art steamship when she left New York on her last voyage.

For days the ship took on water from the raging sea. Sails were shredded. Pumps failed. A hundred miles off the Savannah coast the order was given to "abandon ship."

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For trips that make a difference to you and to the places we visit. Trek Mountain Gorillas, snorkel on Barrier Reefs, rainforest hikes, whitewater rafting, and more.

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Discover a vacation you never knew existed. Discover mountains, prairies, open skies and endless coastlines. Discover it all in your FREE Texas State Travel Guide. Discover why Texas really is like a whole other country.

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The St. Joe Company offers the greatest choice of authentic, organic, and original places to live, work, and escape in Florida.

47. TILLER INTERNATIONAL TOURS INC.
LADAKH SIKKIM BHUTAN—Wondrous eco/cultural tour from arid western Himalayas to the temperate forested eastern range, where Tibetan religion meets the 21st century.

48. TOYOTA
As Toyota continues to expand our U.S. operations, we're working to create even more jobs and opportunities across the country. Learn more about our ten manufacturing plants, sales and marketing operations, design and R&D facilities, and how we invest in local communities.

49. TUCSON
Tucson, Real. Natural. Arizona Discover a whole new side of nature in our fascinating desert landscape. And the weather's perfect for exploring our spectacular scenery any time of year.

50. WORCESTER COUNTY, MARYLAND
Maryland's only seaside county. Visit Assateague Island National Seashore. Kayak, canoe, bird watch or golf. Stay in one of our many Bed & Breakfast Inns.

51. ZEGRAHM EXPEDITIONS
Offers small-group expeditions to remote locations around the world. Expertly led and staffed, our programs provide the finest adventure travel experience imaginable.

(Continued from page 70)

the same place, all you would have to do is measure their respective elemental abundances. If they're roughly the same, it's a good bet the stars are siblings from the same cluster or galaxy.

Two big hurdles, however, have to be overcome to carry out that simple test. First, almost all the matter in the universe is made up of just two elements, hydrogen (about 75 percent by weight) and helium (about 25 percent). All the other elements contribute negligibly to the overall elemental distribution.

Worse, the relative abundances of the elements change with time, because of what goes on inside the stars themselves. Nucleosynthesis—including the energy-producing fusion reactions that make stars shine—turns lighter elements into heavier ones. Furthermore, most of the heavy elements undergo radioactive decay, gradually reducing the abundance of some elements while increasing that of others.

With all that in mind, Brewer and Carney selected twenty-three long-lived, stable stars from the thin and thick disks for study. With the four-meter Mayall telescope at Kitt Peak National Observatory in Arizona and the 2.7-meter Harlan J. Smith telescope at McDonald Observatory in Texas, they spread the visible portion of the light from each of the target stars into highly resolved spectra. The spectra, in turn, yielded the signatures of twenty-four elements for analysis, including a number of trace elements.

Brewer and Carney's painstaking work shows that thin-disk and thick-disk stars have many elemental abundance patterns in common. At the same time, though, the two kinds of stars differ in several critical ways. The differences imply that the oldest thick-disk and thin-disk stars formed independently, but that younger stars from both disks may have formed in roughly the same interstellar conditions.

If Brewer and Carney are correct, a fascinating, unifying picture of galactic-disk evolution emerges—a scenario that, as dwarf galaxies continue to plunk into the Milky Way, may repeat itself in the eons to come. Billions of years ago, a small galaxy began falling into the Milky Way. As the union proceeded, the gas of the small galaxy mixed with the gas already in the Milky Way's thin disk, and new generations of stars formed out of that fresh mixture. It may take a few billion more years for the thick-disk, immigrant stars to settle completely into the staid, swirling thin-disk environment. In the meantime, though, their progeny stars have already begun the process of assimilation. They have taken on some of the chemical characteristics of their new surroundings, yet they still carry the elemental roots and dynamic motions of their extragalactic origins—straddling the boundary between disks thick and thin.

Charles Liu is a professor of astrophysics at the City University of New York and an associate with the American Museum of Natural History.

(Continued from page 12)

views is probably anathema to those who regard the Bible as offering a literal account of the origins of life. Yet, turned against their Darwinian opponents, "teach the controversy" becomes verbal ju-jitsu. The diabolical cleverness of the creationist trap is the almost irresistible appeal it makes to the liberal mind.

But it is quite possible to resist the slogan and avoid the trap. The way out is to note that scientific activity has its own rules of engagement. Yes, of course, science, like any other human activity, can be afflicted with authoritarianism, ego, political strife, vested interests, and the like. But doing science presupposes at least a community whose participants can agree, roughly, about the subject matter of their inquiry, what constitutes relevant evidence, what counts as a valid argument or a convincing refutation. Those shared commitments require time, maturity, and a certain sophistication to develop—hence my insistence on some form of a scientific "union card."

As for what goes on in the science classroom, Peter Starr's proposals seem sensible to me. But it also seems to me both dangerous and discriminatory not to give all students enough exposure to science, say, to enable them to respond as thoughtful citizens to the ethical and social issues posed by scientific and technical advances. If you grant this, then there is little enough time, at the pre-university level, to teach a smattering of well-established science, without wasting effort on long-discredited views. Shall we teach Aristotle in physics class, Ptolemy's universe in astronomy, phlogiston theory in chemistry? So it is with creationism in biology.

Natural History *welcomes correspondence from readers. Letters should be sent via e-mail to* nhmag@naturalhistorymag.com *or by fax to 646-356-6511. All letters should include a daytime telephone number, and all letters may be edited for length and clarity.*

By Joe Rao

Mercury lies low in the western sunset sky during the first several days of March, shining at magnitude 0.8. On the evening of the 1st the planet sets nearly due west about eighty minutes after sunset. It is situated slightly more than ten degrees below and to the right of a young crescent Moon; a clenched fist, held at arm's length, measures roughly ten degrees, and so Mercury should be slightly more than one fist below and to the right of the crescent. The planet passes inferior conjunction (between the Earth and Sun) on the 12th and spends most of March in the glare of the Sun. Late in the month, however, it slowly reemerges low in the eastern dawn.

Venus is the brilliant morning "star" that rises in the east-southeast at about 4 A.M. all month. The glimmering of Venus is a harbinger of daybreak, which arrives less than an hour after the planet rises. During March, Venus dims a bit and loses a little altitude. It reaches greatest western elongation (46.5 degrees from the Sun) on the 25th.

Mars makes its appearance as an extra, first-magnitude "star" in the constellation Taurus, the bull. Late on the evening of the 5th you'll see Mars dropping in the west-northwest sky side by side with a fat crescent Moon. Drifting eastward on the 10th, the planet passes seven degrees north of Aldebaran, which, at magnitude 0.9, is the brightest star in Taurus. That night, the brightness and orange hue of the planet and the star are about the same. By month's end, Mars lies between the horns of Taurus and fades to magnitude 1.2.

Jupiter, in the constellation Libra, the scales, rises at about 11:15 P.M. on the 1st and two hours earlier by the 31st. An hour or two after rising, the planet is well up in the southeast. The best time for observing Jupiter with a telescope is early morning, when it reaches its highest altitude.

Saturn is in an excellent position for early evening observing; it crosses the meridian at about 9:45 P.M. on the 1st and two hours earlier by the end of the month. On the evening of the 10th the waxing gibbous Moon is situated to the east of Saturn. The zero-magnitude planet lies within the boundaries of the faint constellation Cancer, the crab—a star pattern so dull that Kenneth L. Franklin, who for many years was chief astronomer at the Hayden Planetarium in New York City, referred to it as an "empty space" in the sky. Saturn's beautiful ring system is inclined about nineteen degrees to our line of sight.

Path of totality for total solar eclipse on March 29

The Moon reaches first quarter on the 6th at 3:15 P.M. and waxes to full on the 14th at 6:35 P.M. It wanes to last quarter on the 22nd at 2:11 P.M. and becomes new on the 29th at 5:15 A.M. Early risers on the 22nd might note how low the Moon appears in the sky as it crosses the meridian, its highest altitude of the night, just before 6 A.M. The low altitude is the result of its extreme southern declination, an occurrence related to the so-called regression of the lunar nodes (the orbital plane of the Moon wobbles like a top with respect to the plane of the Earth's solar orbit), a cycle that lasts 18.6 years.

A penumbral lunar eclipse takes place on the 14th: the full Moon passes through the penumbra, or outer portion, of the Earth's shadow, causing a faint partial shadow to fall on the Moon's surface. The penumbra is usually hard to see, but during this event it will cover the entire Moon, noticeably tarnishing the Moon's lower limb. Maximum eclipse takes place at 6:47 P.M.; the penumbra's grayish hue should be evident for as long as forty minutes before and after. Although observers in Africa and Europe will have the best views, anyone in the eastern third of North America and nearly all of South America should also be able to spot evidence of the penumbral shadow shortly after the Moon rises.

On March 29 a total eclipse of the Sun passes across Africa and Western Asia. Totality begins at sunrise over easternmost Brazil, and the dark umbral shadow of the Moon then spends the next thirty-six minutes sweeping northeast over the Atlantic. It makes landfall again in western Africa [*see map at left*], continuing its northeasterly trajectory over Ghana, Togo, Benin, Nigeria, central Niger, northern Chad, and central and eastern Libya. Totality is longest—nearly four minutes and seven seconds—along the border between Chad and Libya. After passing over the Mediterranean, the track of the eclipse sweeps through central Turkey, the northwest corner of Georgia, and across Kazakhstan before leaving the Earth at local sunset in Mongolia. A partial solar eclipse will be visible across the rest of Africa (except the southernmost part), Europe, the Middle East, and Western Asia.

The vernal equinox takes place [illegible] P.M. on the 20th. Spring commences in the Northern Hemisphere, autumn commences in the Southern.

Unless otherwise noted, all times are given in eastern standard time.

2006 Isaac Asimov Memorial Debate

Universe: One or Many?

Wednesday, March 29
7:30 p.m.
LeFrak Theater
$14 ($12 Members, students, senior citizens)

Join a panel of cosmologists to debate the possibility that our universe is just one of many universes that make up the "multiverse." This idea presupposes dimensions beyond our everyday experience and draws from the leading edge of our cosmological theories. The presence or absence of data in support of these concepts forms a central theme for the evening.

Panelists:
Michio Kaku, City College, CUNY, author of *Parallel Worlds*
Lawrence Krauss, Case Western Reserve University, author of *Hiding in the Mirror: The Mysterious Allure of Extra Dimensions*
Andrei Linde, Stanford University, theoretical cosmologist and one of the original architects of the multiverse concept
Lisa Randall, Harvard University, author of *Warped Passages: Unravelling the Mysteries of the Universe's Hidden Dimensions*
Virginia Trimble, University of California, Irvine

The late Dr. Isaac Asimov, one of the most prolific and influential authors of our time, was a dear friend and supporter of the American Museum of Natural History. In his memory, the Hayden Planetarium is honored to host the annual Isaac Asimov Memorial Debate—generously endowed by relatives, friends, and admirers of Isaac Asimov and his work—bringing the finest minds in the world to the Museum each year to debate pressing questions on the frontier of scientific discovery. Proceeds from ticket sales of the Isaac Asimov Memorial Debates benefit the scientific and educational programs of the Hayden Planetarium.

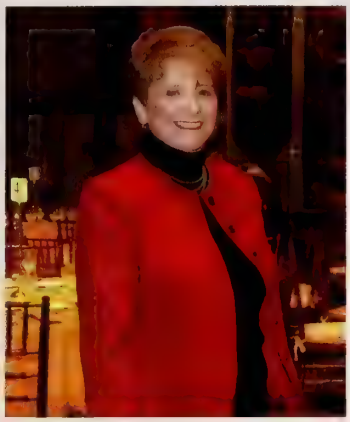
To learn more about this topic in advance of the debate, read "The Self-Reproducing Inflationary Universe," available at **http://www.stanford.edu/%7Ealinde/1032226.pdf**.

© CHESEK AMNH

Host an event at the American Museum of Natural History. Dance on the ocean floor under a 94-foot blue whale, dine with the world's tallest freestanding dinosaur, or drink a toast amid the stars and planets. An event at the American Museum of Natural History is a one-of-a-kind experience every single time—your guests can venture to the edge of the known universe, probe the mysteries of the ocean's depths, or trek into the exotic heart of the rain forest. From cocktail receptions to film premieres, product launches to gala dinners, the Museum offers the perfect backdrop for a distinctive occasion. Call Event and Conference Services at 212-769-5350 or visit www.amnh.org/hostanevent.

PEOPLE AT THE AMNH

Joanna Dales
Associate
Event and Conference Services



R. MICKENS/AMNH

When Joanna Dales was a senior in college, she and her friends visited the Museum. Standing on the steps outside, one of her friends predicted that one day, one of them would live right by the Museum. Years later, Joanna not only lives across the street, but she walks up those very same steps to work every day.

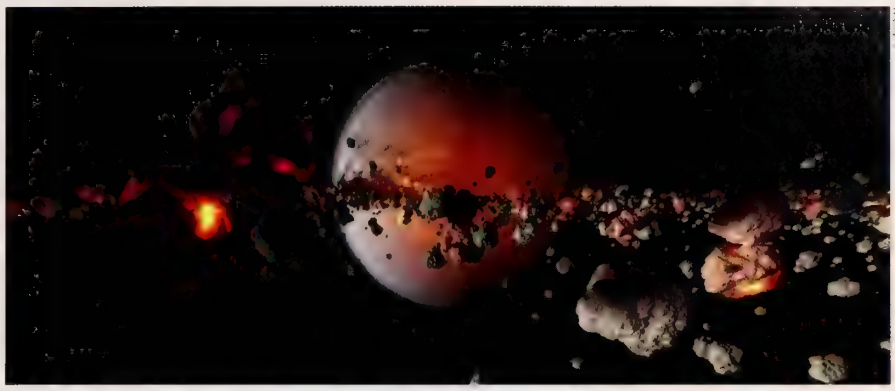
As an Associate in Events and Conference Services, Joanna coordinates special events for the Museum as well as outside clients. She deals with prospective clients, and admits that the most enjoyable part of the process is introducing people to the Museum.

Joanna is on her third career. After obtaining a degree in English, she spent several years as a high-school English teacher before pursuing a career in marketing. She spent over 26 years at *Better Homes and Gardens* magazine, most of the time as Director of Marketing for Advertising. She then briefly ran her own event-planning company before joining the Museum six years ago. "The work I do here really combines all my passions."

When she is not working, Joanna enjoys reading and loves to cook and give dinner parties, the mark of a true event planner. "The greatest satisfaction of the job comes in hearing a client say, 'It went exactly as I had hoped for and more.' That sense of accomplishment is what you go to work for."

COSMIC COLLISIONS

New Space Show at the Hayden Planetarium Opens March 18



AMNH

Cosmic Collisions was created by the American Museum of Natural History with the major support and partnership of the National Aeronautics and Space Administration's Science Mission Directorate, Heliophysics Division. *Cosmic Collisions* was developed in collaboration with the Denver Museum of Nature and Science; GOTO, Inc., Tokyo, Japan; and the Shanghai Science and Technology Museum.
Cosmic Collisions is made possible through the generous support of CIT.

amnh.org Launches New Space Events Web Page

www.amnh.org/space-events

A new Web page, **www.amnh.org/space-events**, is where you'll find the most up-to-date information on space-related events taking place each month at the American Museum of Natural History. Visit often to learn about the Museum's plans to watch the Mars Reconnaissance Orbiter enter orbit around the Red Planet; discover what's happening to observe Sun-Earth Day on Wednesday, March 29; and find out about other late-breaking news, programs, and events in space science.

NASA

Total solar eclipse

R. MICKENS/AMNH

Soh Daiko, a New York–based Japanese *taiko* drum troupe, will welcom[illegible] with a celebratory performance at the **Global Weekends Spring Festival**. On S[illegible]day, **March 19**, a day of workshops, demonstrations, performances, and more will ring in the spring equinox and International Earth Day while educating kids and famili[illegible] about the science and culture of this season of renewal.

Museum Events

AMERICAN MUSEUM & NATURAL HISTORY

www.amnh.org

EXHIBITIONS

***Darwin** Extended!*
Through August 20, 2006
Featuring live animals, actual fossil specimens collected by Charles Darwin, and manuscripts, this magnificent exhibition offers visitors a comprehensive, engaging exploration of the life and times of Darwin, whose discoveries launched modern biological science.

K. FREY/CBC/AMNH

Galápagos land iguana

The American Museum of Natural History gratefully acknowledges **The Howard Phipps Foundation** for its leadership support.
Significant support for *Darwin* has also been provided by the Austin Hearst Foundation, Jack and Susan Rudin, and Rosalind P. Walter.
Additional funding provided by Chris and Sharon Davis, Bill and Leslie Miller, the Carnegie Corporation of New York, Dr. Linda K. Jacobs, and the New York Community Trust–Wallace Special Projects Fund.
Darwin is organized by the American Museum of Natural History, New York, (www.amnh.org), in collaboration with the Museum of Science, Boston; The Field Museum, Chicago; the Royal Ontario Museum, Toronto, Canada; and the Natural History Museum, London, England.

The Butterfly Conservatory: Tropical Butterflies Alive in Winter
Through June 23, 2006
A return engagement of this popular exhibition includes up to 500 live, free-flying tropical butterflies in an enclosed habitat that approximates their natural environment.

This exhibition is made possible, in part, through the generous support of JPMorgan Chase

Voices from South of the Clouds
Through July 23, 2006
China's Yunnan Province is revealed through the eyes of the indigenous people, who use photography to chronicle their culture, environment, and daily life.

The exhibition is made possible by a generous grant from Eastman Kodak Company. The presentation of this exhibition at the American Museum of Natural History is made possible by the generosity of the Arthur Ross Foundation.

Vital Variety
Ongoing
Beautiful close-up photographs highlight the diversity of invertebrates.

GLOBAL WEEKENDS

Spring Festival
Sunday, 3/19, 11:00 a.m.–4:00 p.m.
Join in a day of activities celebrating the vernal equinox and International Earth Day. Visit **www.amnh.org** for details.

Global Weekends are made possible, in part, by The Coca-Cola Company, the City of New York, and the New York City Council. Additional support has been provided by the May and Samuel Rudin Family Foundation, Inc., the Tolan Family, and the family of Frederick H. Leonhardt.

LECTURES

Women of Discovery
Saturday, 3/4, 1:00 p.m.
Meet the five extraordinary women explorers honored as 2006 Women of Discovery Award winners.

Fish on Friday
Thursday, 3/9, 7:00 p.m.
Brian Fagan connects Catholic tradition and the discovery of the New World.

Adventures in the Global Kitchen: Evolution of Taste
Thursday, 3/9, 7:00 p.m.
Explore the evolution of taste and smell with a panel of scholars and writers; a tasting follows.

Cracking the Ocean Code
Sunday, 3/12
2:00–3:00 p.m. Screening
3:15–4:15 p.m. Discussion
Genomics pioneer J. Craig Venter and his team hunt for new life forms and genetic secrets.

Science and Faith
Thursday, 3/16, 7:00 p.m.
A timely panel discussion on the compatibility of religion and modern science.

The Weather Makers
Tuesday, 3/21, 7:00 p.m.
Tim Flannery weaves together complex scientific issues about climate change and global warming.

On the Trail of the Ivory-Billed Woodpecker
Tuesday, 3/21, 7:00–9:00 p.m.
Photographer Bobby Harrison describes his quest for the ivory-billed woodpecker.

The Naming of Names
Thursday, 3/23, 7:00 p.m.
Anna Pavord traces the history of botanical taxonomy through social and scientific spheres.

Windows on Nature
Thursday, 3/30, 7:00 p.m.
Stephen C. Quinn, AMNH, discusses the Museum's famous habitat dioramas and the artists and scientists who created them.

COURTESY OF BEN FAGAN

Ben Fagan

FAMILY AND CHILDREN'S PROGRAMS

Visit the Space Station
Sunday, 3/5, 11:00 a.m.–12:30 p.m. (Ages 4–5, each child with one adult)
Learn about life aboard the International Space Station.

STARRY NIGHTS
Live Jazz

R. MICKENS/AMNH

ROSE CENTER FOR EARTH AND SPACE
6:00 and 7:30 p.m.
Friday, March 3

Visit www.amnh.org for lineup.

Starry Nights is made possible, in part, by Constellation NewEnergy and Fidelity Investments.

Robots in Space I (For Beginners)
Three Wednesdays, 3/8–3/22, 4:00–5:30 p.m. (Ages 8–10)
Design and build robots using the Lego Mindstorm design system.

Dr. Nebula's Laboratory: Light and Optics
Saturday, 3/11, 2:00–3:00 p.m. (For families with children ages 4 and up)
Dr. Nebula's apprentice, Scooter, exposes the mystery of light and its colors.

Space Explorers: Myths and Constellations of the Spring Sky
Tuesday, 3/14, 4:30–5:30 p.m. (Ages 10 and up)
On the second Tuesday of each month, kids (and their parents) can learn under the stars of the Hayden Planetarium.

Wild, Wild World: Predators
Saturday, 3/18, 12:00 noon–1:00 p.m. and 2:00–3:00 p.m.
Live-animal presentation with a golden eagle, alligator, python, and brown bear cub.

Wild, Wild World is made possible, in part, by Mortimer B. Zuckerman.

NASA

"Return to Flight" launch of *Discovery*

NEW! Cosmic Collisions
Thursday, 3/23, 4:00–5:30 p.m. (Ages 8–10)
See the new Space Show and explore the science behind it.

HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME

Virtual Universe
Mars Madness
Tuesday, 3/7, 6:30–7:30 p.m.

This Just In...
March's Hot Topics
Tuesday, 3/21, 6:30–7:30 p.m.

Celestial Highlights
The Bear and the Lion
Tuesday, 3/28, 6:30–7:30 p.m.

LECTURES

Distinguished Authors in Astronomy
Monday, 3/13, 7:30 p.m.

Frontiers in Astrophysics
Monday, 3/27, 7:30 p.m.

HAYDEN PLANETARIUM SHOWS

Passport to the Universe
Closes March 17
Narrated by Tom Hanks

The Search for Life: Are We Alone?
Closes March 17
Narrated by Harrison Ford

Made possible through the generous support of Swiss Re.

SonicVision
Fridays and Saturdays, 7:30, and 8:30 p.m.
Hypnotic visuals and rhythms take viewers on a ride through fantastical dreamspace.

SonicVision is made possible by generous sponsorship and technology support from Sun Microsystems, Inc.

LARGE-FORMAT FILMS

LeFrak IMAX Theater
Galápagos explores the unique fauna of the islands and the surrounding sea.

IMAX films at the Museum are made possible by Con Edison.

INFORMATION

Call 212-769-5100 or visit www.amnh.org.

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 9:00 a.m.–5:00 p.m., or visit www.amnh.org. A service charge may apply. All programs are subject to change.

AMNH eNotes delivers the latest information on Museum programs and events to you monthly via email. Visit www.amnh.org to sign up today!

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As a Museum Member, you will be among the first to embark on new journeys to explore the natural world and the cultures of humanity. You'll enjoy:

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- Free subscription to *Natural History* magazine and to *Rotunda*, our newsletter
- Invitations to Members-only special events, parties, and exhibition previews

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Growing Up in the Treetops

By Margaret D. Lowman, Edward Burgess, and James Burgess

Like most working parents, I wear two hats. In my case, I am a single parent and a scientist. When asked about their mother's occupation, my sons, Eddie and James, usually reply, "Well, she climbs trees for a living." As a rain-forest biologist, I have been on many expeditions to study the canopies of remote jungles, and my boys, of necessity, have often come along. They have lived in remote huts, counted leaves, patiently watched herbivores feeding on foliage, brushed their teeth without running water, eaten mystery stews over campfires, addressed their own hypotheses, and generated their own data sets.

In the Amazon we have dangled from trees together, walked on canopy bridges, learned about medicinal plants from a shaman, eaten insects, spotted scarlet macaws, and just gotten muddy. My children also have an extraordinary tolerance for biology at the dinner table. We talk about insect poop and how to measure it. We bandy about the Latin names of beetles as if they were sports teams. Family debates focus on how to rig new gadgets for sampling in the treetops.

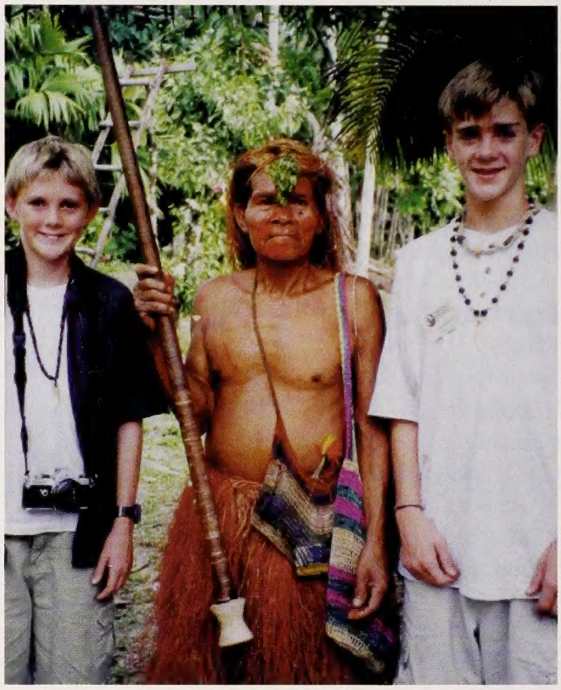
Because my children have been such an integral part of my research expeditions, I am delighted—both as a scientist and as a mother—that the field journals they kept on these journeys record such heartfelt enthusiasm:

Diary of James
Aged 13, Grade 7 (almost)
AUGUST 8. I woke up this morning without an alarm clock; I realized my mom was still asleep. Gosh, she must have been really tired getting all three of us packed, on the plane, and into the jungle. She had just been to Peru three months ago, and now we were back as a family while she taught a summer workshop. I slowly got out of my bed, which was surrounded by mosquito netting, and wondered how anyone could sleep through the noisy calls of the macaws and toucans. Probably the most exciting part about the Amazon is that all around you are millions of species of plants, mammals, insects, birds, and other types of creatures. Some of them have extremely colorful patterns or strange forms. Others have exotic names, beautiful calls, or special physiological features. One thing I learned in the Amazon is that the name does not always indicate how a bird looks. An ornithologist told me about a bird with the longest Latin name in the world—*Griseotyrannus aurantioatrocristatus.* I have been tying to memorize it, but it is tricky. When I went on a bird-watching trip, we saw this bird, and to my dismay it was gray with a slight yellow patch on its head.

AUGUST 9. I went into the canopy for sunrise with my buddy D.C. Randle. It was nearly dark on the forest floor, but when we climbed up all the steps into the canopy, the first rays of morning sun dazzled us. The birds and monkeys up there were also awake and active. Mist was rising from the river in the distance. I wondered if boys my age were out fishing in their dugout canoes, getting breakfast for their families. How different were our lifestyles: they had canoes, blowguns, and soccer balls; we had computers, cell phones, and Nintendo. It might be fun to trade places.

UNDATED ENTRY. In the Amazon, people are different from those in America. In some American cities, it is hard to trust people and to find kindness, but in the jungle everyone is kind and generous. When we visited people in the Amazon, sometimes we traded things. Peruvians had many handmade crafts like knives, blowguns, baskets, masks, necklaces, bracelets, and decorations. The villagers liked to trade for my soccer shoes, T-shirts, or serving spoons, which were not easy to get along the river.

The Amazon is my favorite place on Earth.



James Burgess (left) and his brother Edward (right) trade for blowguns in the Peruvian Amazon.

Eddie and James taught me to think beyond the relatively narrow perspective of analytical science. Experiencing the world through three pairs of eyes has enriched my life far beyond relying on my view alone.

MARGARET D. LOWMAN is a professor of biology and environmental studies at New College of Florida, in Sarasota. Her sons, Edward and James, are students at Princeton University. This story is excerpted from It's a Jungle Up There: More Tales from the Treetops, *by Margaret D. Lowman, Edward Burgess, and James Burgess, which is being published this month by Yale University Press.*

T.rex at the Watering Hole by James Gurney

Isn't there a place in your home for a T.rex?

Dinosaurs have always been bigger than life. . . . and now, these awesome images by award winning artists James Gurney and Douglas Henderson are available as murals for home, school, or office.

T.rex Vs Giganotosaurus by James Gurney

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